Progress in Scientific Radio

FIFTEENTH GENERAL ASSEMBLY OF THE INTERNATIONAL SCIENTIFIC RADIO UNION

September 5-15, 1966
Munich, Germany

REPORT OF THE
U.S.A. NATIONAL COMMITTEE
OF THE
INTERNATIONAL SCIENTIFIC RADIO UNION

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October 28, 1966

Dear Dr. Seitz:

I am pleased to transmit herewith a full report to the National Academy of Sciences—National Research Council, on the 15th General Assembly of URSI which was held in Munich, September 5-15, 1966.

The United States National Committee of URSI has participated in the affairs of the Union for forty-five years. It has had much influence on the Union as, for example, in the recent creation of a Commission on the Magnetosphere. This new Commission, which is now very strong, demonstrates the ability of the Union, one of ICSU's three oldest, to respond to the changing needs of its field.

Although the United States sends the largest delegations of any country to the General Assemblies of URSI, they are nevertheless relatively small because of the strict manner in which URSI controls the size of its Assemblies. This is done in order to prevent ineffectiveness through uncontrolled participation by very large numbers of delegates. Accordingly, our delegations are carefully selected, and comprise people qualified to prepare and present our National Report to the Assembly. The pre-Assembly report is a report of progress in radio science in the United States during the preceding three years (not to be confused with the post-Assembly report herewith). It will be published in the present instance partly in the November 1966 issue and partly in the December 1966 issue of "Radio Science," a journal published by ESSA of the U.S. Department of Commerce in cooperation with the United States National Committee of URSI.

Because participation at the URSI Assemblies is so strongly limited, our Committee feels that it is incumbent upon it to publish a full report of the scientific and administrative proceedings of each Assembly as soon as possible afterwards. Although URSI itself also publishes complete reports, these are very expensive and slow in appearing. Our report is not polished but it is comprehensive, adequately edited, available at our Fall Meeting following an Assembly (held in December in Assembly years), and relatively inexpensive. To accomplish this requires diligent and prompt reporting by many members of the Delegation, much cooperation and assistance from the Academy staff, a subsidy, and above all, much work on the part of our Vice-Chairman on whom the responsibility for editing and producing the report traditionally falls. In transmitting the present report, therefore, I want to express the gratitude of the Committee to all members of its Delegation who served as reporters; to our staff assistant Miss Joyce Hannaum who compiled all the material in Munich and typed a large part of it in preliminary form; to National Aeronautics and Space Administration Headquarters for a very essential subsidy; and above all to our Vice-Chairman

Professor E. C. Jordan of the University of Illinois. The Committee also acknowledges with much gratitude the support of government agencies, particularly the National Science Foundation and the Office of Naval Research, in providing travel funds to a substantial number of persons from academic institutions in the Delegation.

The great value of these post-Assembly reports of the United States National Committee has been widely recognized outside the United States and this time the Union itself is undertaking to report in a rapid and inexpensive manner. If the Union's effort is successful, this may be the last time that the United States Committee itself will mount such an effort.

Lastly, it is my pleasure to inform you that Professor Samuel Silver of the University of California was elected President of URSI; Professor William E. Gordon of Rice University received the van der Pol Gold Medal Award and was elected Vice-Chairman of the Commission on Radio Propagation in Non-Ionized Media; Professor Colin O. Hines of the University of Chicago was elected Chairman of the Commission on the Ionosphere; Professor Henry G. Booker of the University of California at San Diego was re-elected Chairman of the Commission on the Magnetosphere; and Professor Marvin Chodorow of Stanford University was elected Vice-Chairman of the Commission on Radio Electronics.

Yours very truly,

Millett G. Morgan, Chairman
United States National Committee
International Scientific Radio Union
National Academy of Sciences—National Research Council

Dr. Frederick Seitz, President
National Academy of Sciences—National Research Council
2101 Constitution Avenue
Washington, D. C.

Preface

Because of severe restrictions on the size of the delegation to a General Assemby, those appointed as delegates have an obligation to inform their colleagues as quickly as possible on the activities of the Assembly. For this reason the U.S. National Committee of URSI considers the prompt issuance of its report to be one of its major responsibilities to the scientific community. This report attempts to summarize the administrative actions as well as the scientific sessions of the General Assembly. The report itself represents the combined efforts of the entire United States delegation, for nearly every delegate was called upon to report at least one session. The major burden of the task fell to the U.S. Commission chairmen-designate, each of whom, as Chief Reporter for his Commission, was responsible for the reporting of its sessions. Partly because of the thoroughness of the reporting, it has been necessary to condense many of the contributions to keep the over-all size of this report within reasonable bounds. The chief reporters were:

Commission I	Dr. Bruno Weinschel
Commission II	Mr. Arthur B. Crawford (for Dr. D. C. Hogg)
Commission III	Professor O. G. Villard
Commission IV	Professor K. L. Bowles

Commission V	Professor W. Erickson
Commission VI	Dr. R. C. Hansen
Commission VII	Professor H. Heffner

It is a pleasure to acknowledge the unstinting cooperation of each of the chief reporters, and through them to thank all reporters.

It would not have been possible to meet publication deadlines without the generous aid of the National Academy of Sciences staff, and particularly the competent help of Miss Joyce Hannaum, Administrative Assistant, USNC-URSI. She deserves the thanks of the entire National Committee for invaluable assistance in the preparation of this report, both during and after the General Assembly.

E. C. Jordan, Vice-Chairman,
USA National Committee, URSI

Timetable of Plenary and Commission Sessions

Sept. 5	a.m.	Opening Plenary Session
Sept. 9	p.m.	Combined Session - All Commissions

COMMISSION I		Radio Standards and Measurements
Sept. 5	p.m.	Organizational Meeting
Sept. 6	a.m.	Standard Frequency Transmission
	p.m.	Velocity of Radio Waves (joint session with Commission VII)
Sept. 7	a.m.	Atomic Standards of Time
Sept. 8	p.m.	International Comparisons and Standard Connectors
Sept. 9	a.m.	Modern Radio Measurements
Sept. 12	a.m.	RF Measurements at Frequencies Below 1 GHz
	p.m.	Measurements at Frequencies Above 1 GHz Including Optical Techniques
Sept. 14	p.m.	Business Meeting

COMMISSION II		Radio Propagation in Non-Ionized Media
Sept. 5	p.m.	Organizational Meeting
Sept. 6	a.m.	Experimental Analysis of the Atmosphere
	p.m.	Models of the Atmosphere
Sept. 7	a.m.	(See Commission VII)

Sept. 8	a.m.	Theoretical and Experimental Investigation of Propagation in Nonionized Media
	p.m.	Effects of Propagation on the Measurements of Distance, Angle-of-Arrival, and Doppler Effect
Sept. 9	a.m.	Propagation and Radiometry for Millimeter and Submillimeter Wavelengths
Sept. 12	a.m.	Planetary Radio and Radar Astronomical Observations (with Commission V)
	p.m.	Business Meeting
Sept. 13	a.m.	Propagation Below the Earth's Surface

COMMISSION III Ionosphere

Sept. 7	p.m.	First Business Meeting
Sept. 8	a.m.	D-Region Structure and Formation
	p.m.	D-Region Collision Frequencies, Relation to Stratosphere
Sept. 9	a.m.	The Ionospheric F Region and the Magnetosphere (with Commission IV)
Sept. 12	a.m.	Dynamics of the Ionosphere: Over-all Picture and E Region in Particular
	p.m.	(See Commission IV)
Sept. 13	a.m.	Dynamics of the Ionosphere—F-Region Phenomena: Interactions Between Movements of Neutral Atmosphere and Ionosphere
	p.m.	Dynamics of the Ionosphere—F-Region Phenomena: Interactions Between Movements of Neutral Atmosphere and Ionosphere (continued)
	p.m.	Second Business Meeting
Sept. 14	p.m.	New Topics

COMMISSION IV Magnetosphere

Sept. 5	p.m.	Organizational Meeting
Sept. 7	p.m.	General Business
Sept. 8	p.m.	Atmospherics I: Characteristics of Atmosphere at the Source and Propagation (with Commission IVa)
Sept. 9	a.m.	(See Commission III)
Sept. 12	a.m.	Whistlers (with Commission IVa)

Sept. 12	p.m.	VLF Radio Waves and Micropulsations (with Commissions III and IVa)
Sept. 13	a.m.	New Developments
	p.m.	Atmospherics II (with Commission IVa)
Sept. 14	a.m.	Business Meeting
	p.m.	Effects of Nuclear Explosions on Radio-Propagation Phenomena (with Commission IVa)

COMMISSION V Radio Astronomy

Sept. 5	p.m.	First Business Meeting
Sept. 6	p.m.	Filled-Aperture Radio Telescopes
Sept. 7	a.m.	(See Commission VI)
	p.m.	Unfilled-Aperture Radio Telescopes
Sept. 8	a.m.	Radio Techniques
	p.m.	More Synthesis and Techniques
Sept. 12	a.m.	(See Commission II)
	p.m.	Solar Radio Spectroscopy: Interplanetary Plasma
	p.m.	Second Business Meeting
Sept. 13	a.m.	New Radio Telescopes and Galactic Radio Astronomy
	p.m.	Extragalactic Radio Astronomy

COMMISSION VI Radio Waves and Circuits

Sept. 5	p.m.	First Business Meeting
Sept. 6	a.m.	Diffraction and Scattering in Nonionized Media
	p.m.	Coding, Modulation, and Signal Processing
Sept. 7	a.m.	Antennas (with Commission V)
Sept. 8	a.m.	Nonlinear Circuits
Sept. 9	a.m.	Satellite Communications
Sept. 12	a.m.	(See Commission VII)
	p.m.	Linear Circuits
Sept. 13	p.m.	Electromagnetic Properties of Ionized Media I: Source-Free Solutions in Ionized Regions
Sept. 14	a.m.	Electromagnetic Properties of Ionized Media II: Radiation and Scattering in Ionized Regions
	p.m.	Second Business Meeting

COMMISSION VII Radio Electronics

Sept. 6	a.m.	Low-Noise Devices
	p.m.	(See Commission I)
Sept. 7	a.m.	Nonlinear Optics and Laser Radar (with Commission II)
Sept. 8	a.m.	On Continuous-Wave Lasers, Gas Lasers, and Holography
Sept. 12	a.m.	Microminiaturization (with Commission VI)
	p.m.	Solid-State Plasmas, Helicons, and Gunn Effect
Sept. 13	a.m.	Cryogenic Coils
Sept. 15	a.m.	Closing Plenary Session

Contents

Introduction

The fifteenth General Assembly of the International Scientific Radio Union was held in Munich, Germany, during the period September 5-15, 1966. A warm welcome and excellent facilities were provided by the local arrangements committee headed by Professor W. Dieminger, President of the German National Committee, and Vice-President of URSI. The opening plenary meeting, on the morning of September 5, was held in the Residenz, while the closing plenary session on September 15 took place in the Kongressaal of the Deutches Museum. All scientific and organizing sessions were held at the Technische Hochschule in Munich.

Approximately 640 delegates and 125 observers participated in the Assembly. Delegates and observers were present from Argentina, Austria, Belgium, Canada, Czechoslovakia, Denmark, Finland, France, Germany, Greece, Hungary, India, Italy, Japan, the Netherlands, New Zealand, Nigeria, Norway, Peru, Poland, Republic of China, Republic of South Africa, Sweden, Switzerland, Turkey, United Kingdom, United States of America, Union of Soviet Socialist Republics, and Yugoslavia.

The two plenary sessions constitute formally the action of the official delegates as a body. The administrative actions are carried out by the Board of Officers, the Executive Committee, and the Coordinating Committee and are submitted to the Assembly convened in a plenary session for ratification. Various ad hoc and standing committees also hold their administrative sessions during the Assembly. The actions of these various bodies that are of general interest have been summarized in this report in addition to the scientific sessions of the Commissions.

Two memorial lectures were given during the General Assembly. The Dr. J. Howard Dellinger memorial lecture was given by Professor M. G. Morgan, at which time the Dellinger Gold Medal was awarded to Dr. J. H. Chapman of Canada. At this same meeting the van der Pol Gold Medal was awarded to Dr. W. E. Gordon of the United States of America. The memorial lecture in honor of Professor Zenneck was given by Dr. Georg Goubau.

At the opening ceremony, Professor W. G. Beynon of the United Kingdom presented a short talk dealing with the broad field of geophysical science. Because of its bearing on the future of URSI, his address is included herewith in summary. Also included is the report of the Secretary-General of URSI.

Address at Opening Ceremony

PROFESSOR W. J. G. BEYNON*

On 31 December last the observational phase of the International Years of the Quiet Sun (IQSY) ended. This two-year worldwide enterprise with the romantic-sounding title was the fourth international project of its kind in the past century and the second major effort since 1957. Its three predecessors were the First and Second Polar Years of 1882 and 1932 and the famous International Geophysical Year (IGY) of 1957-1958. The IGY and the IQSY were complementary enterprises in that both were conducted on worldwide scales using comparable techniques in the disciplines involved, but they were held at successive maximum and minimum phases of the solar cycle. The IGY covered all the major geophysical disciplines—atmospheric, oceanic, and solid earth—but the IQSY was limited to those disciplines in which the influence of solar activity is dominant.

The reputation of URSI for active participation and leadership in international geophysical projects is widely recognized. In the Second Polar Year of 1932 and again during the IGY of 1957-1958 this Scientific Radio Union played a leading part. It is good to be able to report that this fact is no less true for the IQSY, which has just ended. Thanks to the efforts of its representatives on the international IQSY Committee, Professor Dieminger and Mr. Shapley, actively supported by many specialist members of the URSI - CIG Committee, radio studies of the ionosphere and of the magnetosphere have again been a central and key part of the over-all program.

*President, Special Committee for the IQSY and President, Comité International de Géophysique.

During the IQSY, in the ionosphere discipline alone no fewer than 330 stations made radio observations of one sort or another, and the detailed programs for these observations were drafted by the URSI - CIG Committee. The Inter-Union World Day Service, of which URSI is the mother union, provided all IQSY workers with a carefully compiled detailed Geophysical Calendar, and, as during the IGY, this committee again took care of the Solar and Geophysical Alert system, so necessary for worldwide cooperative studies. The Union owes a great deal to the many radio workers who have done so much to maintain and enhance the high reputation of URSI in the field of international geophysical cooperation, and this is perhaps an appropriate occasion for me as President of the IQSY Committee to place on record not only the appreciation of URSI but also my own personal gratitude for what they have done.

This morning I will not attempt to comment on the scientific fruits of this vast international program—sufficient to say that arrangements are well advanced for a major symposium on the results of the IQSY, to be held in London in July of next year.

In this last decade the world situation in geophysics has indeed changed greatly, and it is, I think, important for URSI to give urgent attention to what is in effect a new and changing situation. The IGY and the IQSY, coupled with the rapid developments in space research, have between them given rise to a tremendous world upsurge of activity and progress. Large numbers of new workers have entered the field and today investigations of the atmosphere, the earth, the geomagnetic field, cosmic rays, and solar phenomena are being pursued in all corners of the world with unprecedented vigor. Networks of observing stations extend over the surface of the globe carrying out special and synoptic observing programs according to internationally agreed plans. Great quantities of data are being accumulated in the 30 or so World Data Centers first established during the IGY. The efforts of workers in 66 countries during the IGY (and 71 in the IQSY) have, without doubt, raised world interest and activity to a new plateau, and although there will now be some slackening off, it is unlikely that the level of activity will ever return to that of pre-IGY years.

This great expansion of activity in geophysics on the national and international fronts has brought certain problems, particularly in the field of solar-terrestrial physics. The first arises from the overlapping interests of a number of international bodies. Recently it was pointed out that there were no fewer than seven international organizations with a direct and active interest in solar-terrestrial

physics. The second problem is linked with the first, viz., the multiplicity of national and international scientific meetings and symposia organized to discuss topics in this field. Fortunately, the International Council of Scientific Unions (ICSU) is very much alive to both these problems and has already taken some steps to deal with them. Last year it established a small group charged in the first instance with regulating the timetable of international scientific symposia in the solar-terrestrial physics area. Later, it is planned to expand this body to enable it to take over on a long-term basis the tasks currently being carried out by the Special Committee for the IQSY. At the same time a number of existing committees and commissions are being dissolved and the scientific unions directly concerned are each considering the problem. For a generation and more, different sections of this field have grown up in one or the other of the scientific unions. There are some merits in the preset setup, but there are also clear disadvantages, and we must see to it that our Union is fully alive to the rapidly changing situation. During this Assembly—at the meeting of the URSI-CIG Committee—we hope to give some preliminary thought to the way in which URSI can most effectively cooperate with the new Permanent Committee on Solar-Terrestrial Physics which ICSU has now established.

The IGY and the IQSY altered the world of geophysics just as surely and as permanently as the two World Wars altered the world of politics, and in a recent letter to the world press the 11 officers of the special committees which organized these projects drew attention not only to the immense scientific achievements of the two enterprises but also underlined the fact that "these worldwide cooperative scientific projects have shown conclusively that however many and serious are the political problems that trouble the human race, it is possible for all the nations of the world to work closely together in great enterprises for the common good." In commending the examples of the IGY and the IQSY to the peoples of all nations these 11 scientists, drawn from East and West, went on to "express the earnest hope that scientific academies and governments everywhere will resolve to place this cooperation in geophysical science on a permanent basis. In so doing, we feel that not only will the rapid advance of geophysical science be maintained but, more importantly, it is certain that this continued close cooperation between men of science from all parts of the world will make a significant contribution to the wider field of human understanding and goodwill."

If these sentiments are right, then indeed we in URSI should in future be satisfied with nothing but the very best possible arrangements for facilitating international cooperation in geophysical science, and, in determining what these arrangements shall be, our Radio Union has a clear and vital role to play.

Report of the Secretary-General

According to custom, it is my privilege to present to the General Assembly a report on the activities of our Union since its last meeting.

During the Tokyo Assembly, which left lasting memories to those who had the privilege to be present, the opportunity of modifying the structure of URSI had been discussed, and also the place occupied by our Union among other scientific unions; a committee was set up to investigate the matter. Consultations undertaken by the committee and discussions during the meetings of the Board of Officers and of the Coordinating Committee have shown that modifications to the structure were not desirable. The major interest of URSI should be based on radio-wave propagation and on all phenomena affecting the propagation; they are numerous and various. The domain has a sufficient area to justify the existence of a particular union and provide sources of activities to its commissions and committees.

This nevertheless does not exclude possible modifications to the ways along which such activities are conducted inside the Union. This matter will be considered by the Executive Committee, which will most probably be led to propose some amendments to the statutes and bylaws.

National Committees

As is well known, the Executive Committee, under the chairmanship of the President of the Union, comprises one representative of each

national committee. At the present time the membership amounts to 34 members, and this number will be raised to 39 if the General Assembly agrees on 5 new adherence applications which were introduced since the end of 1963.

I feel great pleasure in thanking, on behalf of URSI, the national committees for the regularity with which they pay their annual dues. Some of them regularly notify the General Secretariat of their activities; such an example should be followed by all. Too often, it is by chance only that modifications in the membership or even in the Board of National Committees are known.

Before dealing with another matter, I have to mention actions of the Argentine National Committee and of the United States National Committee in the field of publications. The first issues regularly a bulletin in the Spanish language, which is a synthesis of the URSI Information Bulletin. The United States National Committee plays an important role in the drafting of "Radio Science" which in some ways may be considered as a URSI journal.

Commissions and Committees

If national committees, through the Executive Committee, are the administrative body of URSI, the commissions and committees provide the scientific power. As said by our President, the activities of commissions and committees will be shown during meetings included in the program.

Still, I would like to mention the great success met by the Symposium on Planetary Atmospheres and Surfaces, organized by URSI Commissions II and V, with the collaboration of the International Astronomical Union. The meeting was held in Puerto Rico in May 1965 and has been organized by a committee under the chairmanship of Professor W. E. Gordon.

In September 1965, Commission VI, through its Chairman, Professor F. L. Stumpers, has organized in Delft the Symposium on Electromagnetic Wave Theory which was also very successful.

Publications

Among URSI activities, the publications should be mentioned, but to deal with them here would take too much time. Consideration of URSI policy in that field has been entrusted to a special committee, which is asked to submit its conclusions to the closing session.

Finances

The same procedure will be followed for the financial administration of the Union. For the time being I shall limit myself in stating that URSI finances are in good shape and that they give us the possibility to meet today the expenses needed for the Union's activities, which are not limited to the various fields of our commissions and committees, but lead URSI to cooperate with other organizations.

Relations with Other Organizations

UNESCO The most important organization with which we have relations is UNESCO, which commemorates this year its 20th anniversary. During those years, relations with UNESCO have always been of a very agreeable nature. The assistance granted by UNESCO is generally made through the International Council of Scientific Unions, but in some cases financial help has been granted directly to our Permanent Service on Ursigrams and World Days. It should be recalled that in 1963 UNESCO made a special grant which allowed URSI to help about 20 young scientists to attend the Tokyo General Assembly.

It is quite obvious that without the material and moral assistance of UNESCO, some scientific unions would not enjoy their present standing. On behalf of World Science, UNESCO should be thanked for the task accomplished during 20 years.

ICSU I have mentioned the International Council of Scientific Unions, better known as ICSU; we should also express our gratitude to that organization for the efforts made toward the coordination of numerous and various activities of unions and scientific committees.

Unions and Scientific Committees Among unions, we should mention particularly the International Astronomical Union and the International Union of Geodesy and Geophysics, and among scientific committees, COSPAR and the CIG. Due to overlapping disciplines we maintain regular relations with those organizations. The first three of them joined URSI to organize the Inter-Union Symposium on Solar-Terrestrial Physics, which was closed only a few days ago.

It is too early to mention the results of that meeting, more especially as a good number of participants have not yet reached Munich. But we can already state that the meeting was a successful

one due to the efforts made by the organizers. The scientific program was drafted by a committee under the chairmanship of Mr. J. A. Ratcliffe, and the material organization has been in the hands of the Yugoslav National Committee for URSI which took particular care to ensure an atmosphere favorable to scientific discussions.

Inter-Union Commissions and Permanent Services   Collaboration between URSI and scientific unions and committees develops also, but indirectly, through URSI representatives on various inter-union commissions and steering committees of permanent services.

New actions to be mentioned in that field are the dissolution of the Inter-Union Commission on the Ionosphere, after 20 years of a most successful existence for the knowledge of the ionosphere, and the setting up of a new Inter-Union Commission on Solar-Terrestrial Physics.

The Inter-Union Commission on Radio Meteorology organized in 1965 in Moscow a very successful International Colloquium on the Fine-Scale Structure of the Atmosphere.

Among IUWDS activities, we should mention the publication of a new edition of "Synoptic Codes."

It is of some interest to state that since 1965 URSI has had an official representative on the Steering Committee of the Bureau International de l'Heure.

ITU   International organizations with which URSI collaborates are not limited to those operating under the aegis of UNESCO and ICSU, but include others. Among them is the International Telecommunication Union (ITU). This collaboration, officially recognized in 1948, operates through the International Radiocommunication Consultative Committee (CCIR). The directorate of CCIR was entrusted a few weeks ago to a great friend of URSI, Dr. J. W. Herbstreit, Secretary of Commission II. It is for me a pleasant duty to offer him, on behalf of URSI, our warmest congratulations and most sincere wishes for the success of the new task he is assuming.

Gold Medals

In 1963 we awarded for the first time the Professor Balth. van der Pol Medal. That gesture will be renewed during the forthcoming days. It will be followed by the award of a new medal, the Dr. J. H. Dellinger Gold Medal, which has been founded due to the generous initiative of the United States National Committee.

Organization of the General Assembly

A few words should be said on the organization of the General Assembly, which opens today. Since the beginning of 1965, the Board has taken care of that important matter and called a meeting of the Board and of the Coordinating Committee. During the session, our Vice-President, Professor W. Dieminger, who is also President of the German National Committee, was able to learn the wishes of those most interested in the success of the Assembly. After the meetings, Professor Dieminger initiated all customary actions. I will not enumerate all the topics dealt with by correspondence or all actions taken by the General Arrangements Committee.

It may seem premature to congratulate and to thank Professor Dieminger and his collaborators for the success of the General Assembly. All those attending this Opening Session will agree to state that what we have already seen allows us to forecast a successful meeting combining both work and pleasure.

Conclusions

The task of the General Assembly will end by the choice of a country where the XVIth General Assembly shall be held and by the election of new offiers of the Board and of new chairmen of commissons.

Allow me to express the wish that the new Board bring to the performing of its task the same spirit of team and of understanding as the one shown by the Board presiding over this Assembly.

To all those officers, I express my most sincere thanks for the help they gave me; the results are a proof of their mutual understanding and of their full devotion to URSI.

I wish to express my particular thanks to Professor I. Koga; the friendly links which existed previously between our President and myself were strengthened during the preparation of the Tokyo Assembly and during the three years of his presidency. Such links justify the great pleasure I feel in recalling that in November 1963 Professor Koga was awarded the Order of Culture, the highest Japanese Academic Award.

I will conclude in wishing to everybody good work and a pleasant stay in Munich.

E. Herbays

Administrative Actions of the Assembly

The primary administrative units of URSI are the Board of Officers, the Executive Committee, and the Coordinating Committee. The Executive Committee is made up of the officers and the officially designated representatives of the adhering bodies of the countries attending the General Assembly. Each body appoints one such representative who, on those matters over which the Executive Committee has jurisdiction, casts all the votes allocated to his country. The United States, by the authorization of the National Academy of Sciences—National Research Council, was represented by Professor M. G. Morgan, Chairman of the U.S. National Committee; the United States has 6 votes on the Executive Committee.

The Coordinating Committee is composed of the officers and the chairmen of the international commissions and of the standing technical committees. The Coordinating Committee deals with the program of the Assembly and the coordination of the scientific activities of the Commissions.

The composition of the Executive Committee at this fifteenth General Assembly was as follows:

Members of the Board

Prof. I. Koga, President
Dr. R. L. Smith-Rose, Past President
Mr. B. Decaux, Vice-President
Prof. W. Dieminger, Vice-President
Prof. A. Prokhorov, Vice-President
Prof. S. Silver, Vice-President

Prof. Ch. Manneback, Treasurer
Ing. E. Herbays, Secretary-General

Official Delegates

Ing. A. Andreu, Argentina
Prof. W. Christiansen, Australia
Prof Burkard, Austria
Ing. R. Gonze, Belgium
Dr. R. S. Rettie, Canada
Ing. J. Pokorny, Czechoslovakia
Dr. J. K. Olesen, Denmark
Prof. M. E. Tiuri, Finland
Ing. Gen. A. Angot, France
Prof. W. Dieminger, Germany
Prof. M. Anastassiades, Greece
Prof. K. R. Ramanathan, India
Prof. F. Carassa, Italy
Prof. A. Kimpara, Japan
Prof. F. L. Stumpers, the Netherlands
Dr. J. G. Burtt, New Zealand
Ing. C. Romero, Peru
Prof. J. Groszkowski, Poland
Prof. C. Shu, Republic of China
Dr. F. J. Hewitt, Republic of South Africa
Father E. Galdon, Spain
Dr. H. Sterky, Sweden
Dr. W. Gerber, Switzerland
Prof. W. J. G. Beynon, United Kingdom
Prof. M. G. Morgan, U.S.A.
Prof. V. V. Migulin, U.S.S.R.
Prof. D. Bajic, Yugoslavia

Observer: Prof. G. Bognar, Hungary

I. OFFICERS FOR THE PERIOD 1966-1969

Prof. Samuel Silver was elected President to succeed Prof. I. Koga who remained on the Board as Immediate Past President. Drs. Groszkowski, Beynon, and Boella were elected as new Vice-Presidents and Prof. Dieminger continues as the fourth Vice-President.

The present roster of officers is:

President: Prof. S. Silver (U.S.A.)

Vice-Presidents:	Dr. M. Boella (Italy) Prof. W. J. G. Beynon (United Kingdom) Prof. W. Dieminger (Germany) Dr. J. Groszkowski (Poland)
Honorary Presidents:	Dr. L. V. Berkner (U.S.A.) Mr. B. Decaux (France) Mr. J. Ratcliffe (United Kingdom) Dr. R. L. Smith-Rose (United Kingdom)
Treasurer:	Prof. Ch. Manneback
Secretary-General:	Ing. E. Herbays
Past President:	Prof. I. Koga (Japan)

Chairmen and Vice-Chairmen of Commissions:

	Chairman	Vice-Chairman
I	Dr. L. Essen (U.K.) (re-elected)	Dr. M. E. Zhabotinski (U.S.S.R.)
II	Dr. J. A. Saxton (U.K.)	Prof. W. E. Gordon (U.S.A.)
III	Prof. C. O. Hines (U.S.A.)	Prof. K. Rawer (Germany)
IV	Prof. H. G. Booker (U.S.A.)(re-elected)	Dr. J. W. Dungey (U.K.)
V	Dr. J. E. Blum (France)	Dr. C. A. Muller (Netherlands)
VI	Dr. F. L. Stumpers (Netherlands)(re-elected)	Prof. H. M. Barlow (U.K.)
VII	Prof. P. Grivet (France) (re-elected)	Prof. Chodorow (U.S.A.)

II. ACTIONS OF THE EXECUTIVE COMMITTEE

The Executive Committee took the following actions:

1. Approved the recommendations of the Working Group set up to consider the future of Subcommission IVa on Radio Noise of Terrestrial Origin. This report (reproduced in full on pages 18-20) recommends that a new commission on the above subject be established on a provisional basis. National committees will be

asked to appoint official members to the provisional commission, and then nominations and election of officers of the commission will be held by mail.

2. Agreed to the following division of interest areas as arrived at by the Chairmen of Commissions VI and VII:

Commission VI:	Information Theory, Circuit Theory, and Electromagnetic Wave Theory
Commission VII:	Electron Devices, Electron and Plasma Physics, Quantum Electronics

3. Approved the change of title of Commission II from Radio and Troposphere to Radio and Non-ionized Media. (This proposal had been put forward at the Tokyo Assembly too late for Executive Committee approval.)

4. Endorsed the recommendations of the URSI Publications Committee. These recommendations are reproduced on pages 20-22.

5. Proposed to recommend to the General Assembly the recognition of new National Committees of Brazil, Hungary, Mexico, and Nigeria, and provisional recognition of Israel (whose application had not yet been confirmed).

6. Accepted an invitation to hold the 1969 General Assembly in Canada (probably Montreal).

7. Declined an invitation from Poland, but expressed the desire to have the Assembly in Poland in 1972.

8. Accepted the United Kingdom proposal on terms of office of commission chairmen and agreed to modify the statutes accordingly. The proposal is to limit commission chairmen to one term of three years and to provide for automatic succession of a vice-chairman to the chairmanship. Under this new arrangement the vice-chairmen as well as the chairmen would be elected by the General Assembly.

III. ACTIONS OF THE COORDINATING COMMITTEE

The following symposia have been proposed by the various commissions:

Commission I:	Lasers in Measurements (to be held in Poland in 1968)
Commission III:	Ionospheric Drifts (no date or locale)

Commission IV:	Inter-Union Symposium on Magnetospheric Physics in 1968 (in conjunction with a proposed NASA Conference)
Commission VI:	Electromagnetic Theory Symposium, 1968 (Stresa, Italy) Information Theory, 1967 (Athens) Circuit Theory, 1968 (Prague)

Both Polish and Greek locations are provisional pending approval by their governments.

IV. REPORT OF WORKING GROUPS

1. Report of Working Party Appointed to Consider Terms of Reference of the Present Commission IVa on Radio Noise of Terrestrial Origin

Present: Prof. W. J. G. Beynon, Prof. H. G. Booker, Prof. A. Kimpara, Dr. J. P. Voge, Prof. M. R. Rivault.

Prof. R. A. Helliwell, Mr. F. Horner, Prof. H. Norinder, Dr. N. H. Lundquist, Dr. J. K. Olesen, Dr. W. Stoffregen.

It was agreed to recommend to the URSI Executive Committee:

(i) That a new Commission on Radio Noise of Terrestrial Origin be established on a provisional basis with the terms of reference set out in Appendix I. It is suggested that the Executive Committee review the progress of the Commission after the next General Assembly.

(ii) That the statement given in Appendix II be adopted by the Executive Committee as a guide concerning the respective interests of Commission III, Commission IV, and the new provisional Commission referred to in (i).

(iii) That the existing Subcommission on Synoptic Whistlers become a joint working group of Commission IV and the new provisional Commission.

W. J. G. Beynon

Appendix I

Terms of Reference of Provisional Commission of Radio Noise of Terrestrial Origin

Considering the importance of the study of atmospheric radio noise, its relationship to the meteorological factors in the source, its propagation along the earth and through the ionosphere and magnetosphere, and its influence on radio communications and the whistling atmospherics, with particular reference to the characteristics of the source and propagation through the ionosphere and the magnetosphere, the following terms of reference for a provisional commission, Radio Noise of Terrestrial Origin, are recommended.

(1) Frequency Spectrum of Atmospherics. It is recommended that observations be made of the frequency spectrum (uhf to elf) of atmospherics, close to the source and at various distances with the object of studying (a) the characteristics of cloud-cloud and cloud-ground discharges, and (b) the propagation of vlf waves.

(2) Localization of the Sources of Atmospherics. It is recommended that investigations be made of effective methods to localize exactly the sources of atmospherics, with a view to studying (a) the propagation of atmospherics, (b) the stormy weather forecasting, and (c) the geographical distribution of sources.

(3) Intensity of Atmospherics. It is recommended that continuous observations be made of (a) the characteristics of atmospherics, and (b) the amplitude and phase of vlf signals, with a view to studying solar and geophysical influences on the propagation of atmospherics (in collaboration with Commission III).

(4) Interference Caused by the Noise to Radio Communications. It is recommended that the characteristics of atmospherics be investigated statistically and be used to predict the degree of disturbance to various types of communication systems, with a view to minimizing the disturbance of radio communications due to atmospherics.

(5) ELF Noise from Lightning Discharges. It is recommended that the origin of elf emissions from lightning discharges and their propagation be investigated to bridge the gap between geomagnetic micropulsations and the low-frequency end of the spectrum of atmospherics (in collaboration with Commission IV).

(6) Whistlers. It is recommended that the characteristics of whistlers be studied with special reference to the nature of the lightning discharges in which they originate (in collaboration with Commission IV).

Appendix II

Memorandum on the Scopes of Commissions III, IV, and the New Provisional Commission on Radio Noise of Terrestrial Origin

The juxtaposition of interests of Commissions III and IV on the ionosphere and magnetosphere is to be determined by the chairmen of the two commissions for each assembly of URSI.

For each assembly there will almost certainly be an area of more or less exclusive interest for Commission IV and an area of overlap that will be handled in joint sessions of the two commissions.

There is little doubt that Commission III will cover all aspects of ionospheric physics involved in radio communication via the ionosphere between different parts of the earth. There is little doubt that Commission III will also cover the physics of the formation and disappearance of the D, E, and F layers of the ionosphere, including the phenomena of geomagnetic control of the F region, but at what height Commission III will cut off coverage is undetermined.

There is little doubt that Commission IV will cover all wave phenomena in the outer plasma envelope of the earth for which an earth radius is a signficant unit of length. This includes whistlers, vlf emissions, elf emissions, hydromagnetic waves, interaction between waves and fast particles, and the influence of the normal and abnormal features of the solar wind on the earth's atmosphere. In particular, it is a function of Commission IV to study magnetic storms and auroras regarded as features of solar system physics, although Commission III will be concerned with certain consequences of these phenomena in the D, E, and F regions of the ionosphere. It is certainly a prime function of Commission IV to study the physics of the magnetosphere, defined as the region of the earth's plasma envelope where control of the charged particles by the earth's magnetic field plays a significant role. Since this control probably extends into the F region but not into the E region, Commission IV must to some extent be concerned with the F region. However, most of the work of Commission IV will be concerned with the part of the atmosphere above the level of maximum electron density in the F region.

In summary, it may be said that certain aspects of the phenomena associated with the top and bottom sides of the F region will have to be examined by the Chairmen of Commissions III and IV for each assembly and joint sessions arranged accordingly. Most other phenomena concerned with the earth's plasma envelope will probably be automatically classified as III or IV.

Insofar as the study of elf noise, vlf noise, and whistlers is directed toward the understanding of the magnetosphere, such work shall be included in Commission IV. A working party at the 1966 General Assembly has recommended the establishment of a new provisional Commission on Radio Noise of Terrestrial Origin and the terms of reference of the new Commission have been specified. When necessary, joint sessions of the new Commission and Commissions III and IV could be arranged to deal with topics of common interest. Such sessions would also include man-made phenomena of a similar nature. However, the new Commission would also be concerned with the special characteristics of lightning discharges that produce whistlers, whereas Commission IV ordinarily would not. Furthermore the new Commission would hold sessions to deal with the following items: frequency spectrum of atmospherics, localization of the sources of atmospherics, intensity of atmospherics, interference cuased by noise-to-radio communications, and new unknown radio-noise phenomena.

On the above basis it is thought that Commission III, Commission IV, and the new provisional Commission on Radio Noise of Terrestrial Origin will be able to function efficiently.

2. Report of URSI Publications Committee

Two meetings of the Committee were held, on September 6 and September 12, 1966.

Present: Prof. S. Silver (Chairman), Col. Herbays (Secretary-General of URSI), Mr. G. M. Brown, Prof. C. Burgess, Prof. L. Felsen, Prof. J. Groszkowski, Prof. V. Siforov, Dr. F. L. Stumpers, Mr. M. Thuê.

The subject of the first meeting was the publication of the Proceedings and the Technical Papers of the General Assembly.

It was decided to recommend to the Executive Committee that the publication of the Proceedings of the Assembly should be handled by the URSI Secretariat as in the past.

Progress in Radio Science. There was a consensus that the technical papers of the Assembly should continue to be published as "Progress in Radio Science" in book form, but it was essential that publication be much more rapid and cheaper than hitherto. The following specific points were recommended:

(1) A Photolithographic method of reproduction from typescript should be used.

(2) Publication in two volumes is suggested as follows: (a) Commissions I, VI, VII (b) Commissions II, III, IV, IVa, V.

(3) Scientific editors should avoid extensive editing of texts (unless essential for clarity) and should exclude photographs of equipment unless they are specially informative.

(4) If reports on discussions are to be included, scientific editors should be free to distil the main points and avoid verbatim reports.

(5) Reports on contributions other than invited papers should be summarized by the chairmen of commissions and only these summaries should be published.

At the second meeting it was agreed that October 15, 1966, is the absolute deadline date for the receipt of all manuscripts for publication in "Progress in Radio Science." The mechanics of retyping manuscripts, reproduction, binding, and distribution of the books will be handled by Professor Silver and Colonel Herbays.

It was recommended that one free copy of each volume be sent to the members of the Board of Officers, to each national committee chairman, and to the chairman, vice-chairman, and scientific editor of each Commission. Arrangements for availability of reprints to individual authors are to be explored in making the contractual arrangements with the publishing firm.

URSI Information Bulletin. It was recommended that the present procedures of publication and distribution should be continued, but that one copy should be sent by air mail to each national committee.

Papers for General Assemblies. It was recommended that the present procedure of publishing national committee reports in the proceedings of general assemblies be continued, but that for the present Assembly an exception should be made to the 4,000-word limit in the case of the U.S.S.R. Report and that this should be published in full.

It was recommended that each national committee should send one copy of its report directly to every other national committee prior to the General Assembly. There was a feeling that some means should be found of effecting a wider distribution of national committee reports at general assemblies.

The rules regarding the presentation and publication of papers other than invited review papers were discussed, and it was recommended that the Coordinating Committee be asked to review the present procedural practices.

It was also recommended that a wider dissemination of all papers at general assemblies is desirable.

Finally, it was recommended that the Coordinating Committee, or other designated bodies, be directed to revise the document entitled "Instructions to Authors," with the objective of ensuring more uniformity in presentation of material.

3. Report of the Working Group on Relations with COSPAR and of the Space Radio Research Committee

Working Group (present): Prof. Beynon, Prof. Dieminger, Prof. Silver (convenor), Mr. Voge. Dr. Friedman, Dr. Minnis, and Prof. Morgan were invited as consultants.

Space Radio Committee Meeting (present): Prof. Beynon, Prof. Dieminger, Prof. Siforov, Prof. Maeda, Dr. Hirai, Dr. Ranzi, Mr. A. Shapley, Mr. Essen (Commission I), Mr. Voge (Commission II), Prof. Bowhill (Commission III) for Mr. Ratcliffe, Prof. Booker (Commission IV), Prof. Hagen (Commission V), Dr. Stumpers (Commission VI).

The first meeting of the working group was called on September 7 at 1230 hours. The subjects of the meeting were the relations between URSI and COSPAR and the proposal sent to Professor Silver by Professor Kaplan, President of the UGGI, to create a new union.

The Chairman, Professor Silver, reviewed his experience as the URSI representative on the Executive Council of COSPAR over the first three years (reference report by S. Silver to the Executive Committee of URSI). He expressed the opinion that considerable progress had been made in developing cooperation between URSI and COSPAR, particularly in setting up and organizing symposia in the scientific program of COSPAR. The weak points in the

relation between the unions and COSPAR are the way the meetings of the Executive Council of COSPAR are conducted and the poor liaison between the working groups of COSPAR and the commissions of URSI concerned with the same or closely related problems.

After a very effective exchange of views among the members of the URSI working group,and, in particular, the explanation by Dr. Friedman of several points, the group decided to submit to the Executive Committee of URSI the following recommendations:

(1) To transmit to Professor Roy, President of COSPAR, a letter from URSI expressing our desire to work with COSPAR in the most cooperative and collaborative manner; to express our appreciation of the progress that has been made in our relations and to do what we can to make further progress.

(2) To recommend a revision of the operation of the Executive Council to give the unions most directly concerned with the scientific fields of COSPAR a weighted voting power; to suggest further that the meetings of the Executive Council be made more substantive with respect to the participation of the unions.

(3) That URSI take steps to ensure the presence of URSI members at the COSPAR meetings and arrange for representation at meetings of the working groups as well as in the Executive Council and the special symposia (see more details on this below).

The second meeting of the Working Group was called on September 9th at 1215 hours in conjunction with the Space Radio Research Committee (SRRC). The subject of discussion was the future of the SRRC itself. A review of the activity over the past three years and, in particular, the lack of responsiveness of the members, with few exceptions, was a poor recommendation for the need for such a committee.

The opinions—all present expressed their views on the matter—ranged from having a small committee to having no committee. All agreed that it is necessary to stimulate the interest and activity of the commissions in space research and that a general session such as was held at this Assembly is a most desirable thing. But it was noted that these ends can be met by the Coordinating Committee and, indeed, the action taken by the Coordinating Committee in March 1965 in effect made the Space Research Committee identical with the Coordinating Committee.

It was noted further that one of the most important points is to effect greater interaction of the commissions of URSI with the relevant working groups of COSPAR. There are many members of the working group of COSPAR who are also associated with the

commissions of URSI, but there seems to be little carry-over from one activity to the other. The URSI Working Group and SRRC felt that the interaction will be increased by ensuring that the chairmen of commissions such as II, III, IV, and V attend the COSPAR assemblies, and that the URSI representative to the Executive Council is a member of the Board who is close to and knowledgeable about space research.

The Working Group and SRRC thus make the following recommendations:

(1) That the former SRRC of URSI be discontinued.

(2) That a member of the Board of Officers be designated as the URSI representative to COSPAR; if none is qualified, that a special representative having the requisite qualifications be named.

(3) That it be made mandatory on the URSI representative and the Chairmen of Commissions II, III, and IV, which are most directly related to the working groups of COSPAR, to attend the meetings of COSPAR and collectively to report to URSI on the administrative and scientific activities.

Chairmen of the other commissions may be included according to the program of the COSPAR Assembly. Members should not send "representatives" in their stead unless it is really impossible for them to attend. If it does become necessary to send a substitute, the member should notify the Board and the URSI representative on the Executive Council of COSPAR.

The URSI budget should provide funds for this purpose.

(4) The Coordinating Committee should have the subject of Space Radio Research as a standing item on its agenda.

(5) The program of the General Assembly should provide for a general session in which highlights in radio science (space research or other fields) are presented to all the commissions.

24 4. Commission IV. Report to the Closing Plenary Session of the XVth General Assembly in Munich, 1966

The most interesting activity of the magnetosphere commission of URSI took place just before the Assembly. This was the Belgrade Symposium on Solar Terrestrial Physics, where 180 papers on the magnetosphere and the solar wind were presented, in addition to 20 papers dealing with the ionosphere and the magnetosphere.

In Munich there have been three scientific sessions devoted primarily to the magnetosphere, including one highly interesting

session dealing with recent developments. There have also been two joint scientific sessions devoted to the ionosphere and magnetosphere, as well as two sessions on atmospherics that will be reported by Dr. Kimpara.

Specific actions by Commission IV during this Assembly are the following:

(1) Commission IV believes that the recent Inter-Union Symposium on Solar-Terrestrial Physics in Belgrade should be followed by an Inter-Union Symposium on Magnetospheric Physics in 1968. Such a symposium is understood to be under consideration by the National Aeronautics and Space Administration in the United States.

The proposed topics are: (a) inner radiation zone; (b) outer radiation zone and outer magnetosphere; (c) auroral zone and polar cap; (d) magnetospheric models; (e) geomagnetic tail; (f) magnetopause, magnetosheath, and shock front.

Commission IV recommends that URSI participate in the proposed Symposium on Magnetospheric Physics in 1968 and inform the Inter-Union Commission on Solar-Terrestrial Physics of URSI's desire to participate. Commission IV further recommends that the following item be added to the list of topics: (g) interaction between waves and particles.

(2) Commission IV recommends that interaction between waves and particles be more explicitly recognized by the new Inter-Union Commission on Solar-Terrestrial Physics as one of its organizational disciplines. This discipline includes:

(a) The interaction between the solar wind and the magnetosphere, particularly instabilities, discontinuities, and irregularities at the interface between the solar wind and the magnetosphere, and the waves into which the instabilities, discontinuities, and irregularities may be analyzed.

(b) The relation between whistlers, vlf noise, micropulsations, and energetic particles.

(c) The interaction between ambient particles, ion and electron acoustic waves, and radio waves, which is a topic usually known as incoherent scatter.

These are matters of particular interest to Commission IV, and the Commission would like URSI to request the Inter-Union Commission on Solar-Terrestrial Physics to recognize them more explicitly as one of its disciplines.

(3) Commission IV recommends that its Subcommission on Synoptic Whistler Observations continue for a further period of three years, but become a working group, or Subcommittee, of the URSI Solar-Terrestrial Physics Committee that is replacing the URSI Geophysics Committee.

(4) The Subcommission on Synoptic Whistler Observations has made the following recommendations that have been endorsed by Commission IV:

Recommendation 1. Measurement of Noise at ELF and Lower Frequencies. It is recommended that observations of noise phenomena at elf and lower frequencies be carried out as far as possible in accordance with procedures that have been agreed upon by the subcommission and which will be published in the URSI Bulletin.

Recommendation 2. Recording and Data-Reduction Techniques. It is recommended that research workers studying whistlers and emissions at vlf and lower frequencies be urged to publish, or otherwise make readily available, the details of their techniques for recording and interpreting their data. Relevant technical material that is not in published form should be submitted to the World Data Centers through the chairman of the subcommission.

Recommendation 3. Amplitude Calibration of Noise Recorders. In view of increasing interest in the relative amplitude of whistlers and emissions at different stations, workers are urged to make known the amplitude calibration of their records and to state the amplitude of the inherent noise level of their equipment as it appears on the records.

(5) In response to a request from CCIR, the Chairman of Commission IV, acting on behalf of Commissions III, IV, and V has appointed a working group on the Radio Noise Environment of Spacecraft. Dr. T. R. Hartz of Canada is Chairman, and, with the help of 14 other people, he will provide to the Secretary-General by March 1, 1968, a report for the approval of the Chairmen of Commissions III, IV, and V and for transmission to the Director of CCIR.

(6) The magnetosphere commission approves of the proposal to replace its present Subcommission IVa on Radio Noise of Terrestrial

Origin by a full commission, Commission VIII, on the same subject. The magnetosphere commission wishes to make it clear, however, that, insofar as the study of elf noise, vlf noise, and whistlers is directed toward understanding the physics of the magnetosphere, such work must be the province of Commission IV.

Henry G. Booker
Chairman, Commission IV

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SPECIAL SESSION OF SEPTEMBER 9 (P.M.)

N67-16002

General Session–All Commissions

CHAIRMAN: S. SILVER (U.S.A.)

This special session of all the commissions of URSI (the only such session during the 15th General Assembly) was designed to provide a synopsis of work going on in COSPAR, to give highlights from the Belgrade Symposium on Solar-Terrestrial Physics, and to supply progress reports in two fields:

1. Synchronization of clocks by means of satellites.
2. Unique radio frequencies from space.

Professor Silver first described how the special session would be organized. The part of the session before the break would cover COSPAR and clock synchronization, that after the break would be concerned with the Belgrade symposium and with the new natural lines observed by radio astronomers. He then gave the first of two reports (the second was given by Professor Bowhill) on a COSPAR symposium of interest to URSI during the past three years.

Report on COSPAR 2.4 Symposium—Professor Silver

Professor Silver listed the recent COSPAR symposia: Florence, Italy, in 1964; Mar del Plata, Argentina, in May 1965; Vienna, Austria, in May 1966.

A report on the administrative interactions of URSI and COSPAR has been prepared by Professor Silver and is generally available. A symposium at the Mar del Plata meeting had as its theme the Design of Experiments. This symposium had been conceived as one connected with the URSI General Assembly, but it had ended up with COSPAR. The papers present at the symposium fell into

two categories concerned with (1) acquisition of data by sensors and transmission of these data to the earth, and (2) the question of whether the large orbiting observatory or a series of small satellites is preferable.

It was found that there is a place for each kind of satellite, and the first part of the Mar del Plata symposium was concerned with the concept of an experiment per se. What is meant by a space experiment? One definition is certainly that in which the experimenter has no knowledge of the nature of the phenomena he wishes to observe. He is therefore just listening in space, usually over a wide spectrum, and he frequently floods his home laboratory with a mass of data which accumulate faster than they can be reduced. The problem, then, is whether the experimenter can ask the question in such a way as to minimize the data that need to be collected.

The second part of the Mar del Plata symposium was concerned with the interpretation of satellite data. If the phenomenon to be observed is stationary in time, there is no problem. If it is time-varying, however, the person reconstructing the observations must consider the finite velocity of the satellite.

Report on COSPAR R2 Symposium—Professor Bowhill

This symposium, held May 16-18 in connection with the Vienna 1966 COSPAR meeting, was titled Interaction between the Neutral Part and the Ionized Part of the Atmosphere. Six topics were covered:

1. Neutral atmosphere and apparent ionosphere motions: Emphasis was on comparison of rocket and ground-based experiments. Among the contributors to this session were Webb, Boville, Hines, Elford and Roper.

2. Movements of irregularities and ions: Emphasis was on the distinction between motions of the neutral and ionized constituents and the scale sizes involved. Active in this session were Heisler, Wright, Gossard, Lüst, Martyn, and Spizzochino.

3. Wind shears and the sporadic-E layer: Here an attempt was made to review experimental evidence and evaluate theoretical explanations. Active in this session were Whitehead, Storey, Axford, Bedinger, Smith, Narcisi, Biondi, and others. It was found that the participants were not in agreement as to whether the experimental data substantiated the wind-shear theory. Definite evidence

was presented of the association of heavy ions with certain sporadic-E layers. More comprehensive experiments, however, need to be carried out.

4. Photochemistry and the transport of Minor mesospheric constituents: Emphasis in this session was on the recent rocket airglow and ion mass spectrometer data, which have shown many interesting and surprising results in the mesosphere. Active in the session were Blamont, McElroy, Donahue, London, Narcisi, and Reid. From the ionosphericists' viewpoint we are now finding ourselvers in the awkward position where the electron density in the lowest ionosphere is almost insignificant from the standpoint of understanding the physics and chemistry of the medium.

5. Stratosphere-ionosphere coupling: Remarkable correlations between stratospheric temperature and pressure changes and electron density changes in the D-layer have been observed. Tentative explanations were offered and related to atmosphere dynamics. Active in this discussion were Lauter, Dieminger, Gregory, Beynon, Shapley, Bowhill, and Trisca.

6. Turbopause changes and their effects: Recent theoretical and experimental work was reviewed, which shows that the intensity of mixing in the upper turbosphere can greatly affect the composition of the thermosphere. Active in this session were Johnson, Coté, Rishbeth, Kondrotyev, and Nier.

The program committee for the R2 Symposium consisted of Bowhill (Chairman), Blamont, Carver, Groves, Krassovsky, Lauter, Nagata (representing UGGI), and Silver (representing URSI). The papers were all invited reports, and attention was restricted to heights under 200 km.

41 SYNCHRONIZATION OF CLOCKS VIA SATELLITES

W. Markowitz (U.S.A.)

General

Artificial satellites may be used for the transfer of precise time and frequency in two ways: (1) as a relay system, and (2) as a clock-carrying device.

Method (1) may be used in several ways; for example: (a) a single ground station disseminates time and frequency information to

other ground stations via the satellite; (b) two stations interchange time signals; or (c) one station receives its own signal after retransmission from the other, along with a signal from the other station.

For methods (2) and (1a) it is necessary to know the ranges accurately for clock synchronization, and the range rates can be determined electronically, an added complication, or by use of an accurate ephemeris. Synchronous satellites, such as Syncom, have small changes in range and rate and offer a theoretical advantage.

For method (1b) it is necessary that the relative epochs of the observations at the two stations be known fairly accurately. To assure an accuracy of 0.01 μsec in synchronization, it may be necessary to time the photographs to 0.002 sec.

Method (1b) requires that readings made at the two stations be combined.

With method (1c) the station that does not retransmit determines alone the time difference between the clock pulsers at the two stations. A correction is required for motion of the satellite between transmission and retransmission. The correction is small and can be computed accurately from an ephemeris, even if of low precision. The epoch of observation need be known only to about 5 min.

Method (1b) was used to relate clocks between the U.S.A. and England and (1c) between the U.S.A. and Japan.

Experiments

Joint experiments with Telstar 1 using (1b) were carried out in August 1962 by the National Physical Laboratory at Goonhilly Downs, England, and at the U.S. Naval Observatory at Andover, Maine. Visual recordings were made at Goonhilly and photographic recordings at Andover. The probable error of one recording was 3 μsec and 0.36 μsec, respectively. Pulses from Goonhilly were retransmitted at Andover and received at Goonhilly in one experiment, which gave an immediate determination of the propagation time.

Experiments with Relay 2 using (1c) were carried out in February 1965 by the U.S. Naval Observatory at Mojave (U.S.A.) and by the Radio Research Laboratories at Kashima, Japan. In one part of the pass, Mojave pulses were retransmitted by Kashima, which also injected its own pulses. Mojave's oscilloscopes displayed three pulses: (1) Mojave transmitted, (2) Mojave retransmitted by Kashima, and (3) Kashima transmitted. In another part of the pass, Mojave retransmitted the Kashima pulses. Two independent time differences between the clock pulsers were thus obtained.

The agreement between Mojave and Kashima results indicates a probable error of 0.035 μsec for one photograph and 0.01 μsec for one pass. A correction for ground station delays in transmitter and receiver circuits was not determined but can be made in the future.

Cesium beam atomic clocks at Mojave and Kashima, traveling atomic clocks, and also vlf transmissions were used as checks.

Analysis indicates that the pulses at the ground stations were related to ±0.1 μsec.

Continuous Wave

Measurement of a zero crossing of a continuous sine wave is an alternate to the beginning of a pulse. This method was used by NASA in October 1964 and March 1965 with Syncom in experiments between the Philippines and California. Eight frequencies were used to resolve ambiguities. Difficulties with phase reversal limited the accuracy to about 30 μsec.

Clock-Carrying Satellites

Experiments of method (2) were made in October 1963 by the U.S. Naval Observatory with satellite 63031, developed by the Applied Physics Laboratory. The internal probable error for one pass was 33 μsec. Synchronization experiments with GEOS, which carries a clock, will be done by NASA.

Discussion

The use of communications satellites to synchronize between ground stations to about 0.01 μsec appears feasible. This would provide frequency calibration from time differences of 1 part in 10^{13} in one day. It is not known whether pulses or cw offer significantly higher precision.

UNIQUE RADIO FREQUENCIES FROM SPACE

A. H. Barrett (U.S.A.)

There was a discussion of radio frequency allocations at a Commission V meeting held at the URSI General Assembly in Tokyo, 1963. Up to 1961 only 1 radio astronomy line had been detected,

that of 21-cm wavelength, all attempts to measure other lines having been negative. However, during the past five years, 13 to 15 lines have been observed, and there is considerable urgency for allocation of appropriate protected frequency bands.

The recent observations are of considerable interest. In 1963, the absorption of the OH radical in interstellar space was detected. There were three confirming characteristics of these measurements that were predicted and observed: (1) small OH-radical abundance; (2) large transition probability, making the absorption measurable; (3) a known frequency of emission. Line splitting resulting from the nuclear spin of the hydrogen constituent of the OH radical was observed, consisting of 18-cm radiation. Hyperfine structure from electron spin levels gives rise to 4 lines in the neighborhood of 1,650 MHz. These would normally have a 1:5:9:1 intensity ratio.

The observed ratios differed from the expected ones, and it was found that in regions where hydrogen is strongly absorbing, the OH radical is not. In fact, the OH emission was so anomalous that it was suspected that a competing line was present, most intense at the frequency of the strongest OH line (at 1,665 MHz). Surprisingly, it was also established that the OH emission is circularly polarized to a varying extent up to 100 percent and that the source sizes were very small, with the radiation emanating from H II regions centered within our galaxy.

The spectra were found not to be consistent in shifts (as well as amplitudes) at the four frequencies, and the thermal broadening was only 3°-5°. The time variation of emission/absorption has been monitored. Intensity anomalies among the four lines up to factors of 100 have been found. Brightness temperatures up to $1{,}300^\circ$ K were estimated. The angular source widths were less than 5 minutes of arc. The OH absorption is not polarized. OH is moving toward the galactic center, while H is moving away from it. There is the possibility of explaining some of these observations by the mechanism of masering action.

It is recommended that all the OH frequencies be reserved: 1,612, 1,665, 1,667, and 1,720 MHz. The hydrogen-line frequency allocation problem is not so alarming, because these lines are abundant and there is hope of finding some in presently reserved radio astronomy bands.

After Professor Barrett's talk, Dr. F. G. Smith asked the following questions: (1) If it is not possible to protect all four frequencies, which should be selected for protection? (2) Should

deuterium (327 MHz) continue to be protected? Barrett: (1) It is not yet possible to say, for two or three of the four frequencies. (2) Astrophysicists think that the deuterium abundance should be vastly less (1/13,000) than that on earth (reserved judgment).

REPORT ON BELGRADE SYMPOSIUM ON SOLAR-TERRESTRIAL PHYSICS

Part 1—H. G. Booker (U.S.A.)

The Belgrade Symposium and its Background

The idea for the Belgrade symposium originated at the Tokyo URSI meeting. It was felt that too many international bodies were holding too many meetings and that there was a need to coordinate the content of fewer meetings. A program committee composed of representatives of URSI, IUGG, and COSPAR was formed (J. A. Ratcliffe (U.K.), Chairman; J. W. King (U.K.), Secretary).

A summary of the papers presented at Belgrade indicates that about half the papers were presented by the authors, the remainder by reporters. The symposium topics were: solar wind, quiet magnetosphere, disturbed magnetosphere, energetic particles, and temperatures of atmospheric constituents. Review papers are to be published on these subjects. The most popular among the topics was the disturbed magnetosphere. The interest in the magnetosphere is evidently much more widespread than within URSI alone, and sponsorship of meetings on this subject should not be solely by URSI.

Part 2—J. Dungey (U.K.)

Apparent Current Understanding of the Magnetosphere

There was some sentiment at the Belgrade symposium that the theory of the magnetosphere is closer to reality than are the experimental observations. The theoretical beginning of magnetosphere theory can be traced back to the Chapman and Ferraro theory. Later theory (e.g., the Beard model) has been largely confirmed by observations in the equatorial region, but satellites have not traveled farther than about 8 earth radii outward from

the polar region so that the theory cannot be confirmed there.

Collision-free shocks are treated by many theorists. These have weak turbulence inside the shock and strong turbulence outside the shock. Early treatment of these shocks did not invoke turbulence. An exciting development is that the proton distribution in the solar wind has been found to be anisotropic—i.e., it contains some mild turbulence to begin with. Electrostatic waves of short wavelengths should be present and could be investigated by studying rapidly varying electric fields. To separate the space and time variations of the shock, a group of co-rotating satellites is needed.

There is a controversial question of the reconnection of magnetic lines of force. Are the lines of force from the sun attached to the earth or are they closed? Convection of the magnetosphere as a whole is caused by the reconnection process. Convection is indirectly measured by ground-based magnetic studies.

Part 3—S. A. Bowhill (U.S.A.)

Neutral and Ionized Constituents in the Ionosphere and Magnetosphere

In their reviews, Evans (U.S.A.) and Gringauz (U.S.S.R.) summarized knowledge of neutral and ionized temperatures. The following summary is confined to the temperatures of ionized particles, and temperatures at high latitudes are not considered.

Temperature measurements by various techniques have reached the stage where mutual agreement between techniques is conceded. The electron temperature is found to be about two or three times the neutral temperature. Consideration needs to be given to the mechanism by which the electrons become heated and the consequences of the heating.

There are four observatories providing T_i, T_e/T_i, and N_e information obtained from the spectrum of incoherent scatter (Jicamarca, Arecibo, Millstone, and Prince Albert). The new technique of incoherent scatter has only begun to yield information. Now it is providing measurements not only of the F region, but also of the D and E regions and the ionosphere out to heights of 10,000 km. The "plasma line" has been discovered in the incoherent scatter signal, and an outstanding result is that this line is reinforced by hot photoelectrons coming from the conjugate point. The French incoherent scatter installation at Nançay is now operating, providing good resolution but restricting study to one height at a time.

Reliable satellite observations of T_e and T_i are very complete at 1,000 km (Explorer 22), giving temperatures as a function of latitude and time. The proton whistler technique, based on ion cyclotron waves, is giving information as to T_i in the F region. Rocket results are no longer the prime source of electron temperature measurements.

The theory has not had to be modified appreciably as a consequence of the experiment: tubes of ionization containing interpenetrating fluids of electron, ion, and neutral gas, wherein heat is injected by the sun, then conducted and exchanged. What is still needed is the conductivity along the field lines of the electron and ion gas and of the neutral gas. The nighttime ionosphere is kept comfortably warm by heat dribbling down the tubes of force.

Three results are noteworthy:

(1) Cohen (U.S.A.) and Hanson (U.S.A.) find that only 2 eV are liberated when photoionization occurs.

(2) Farley (U.S.A.) finds (at the magnetic equator) an upper limit on T_e at about 400 km (heat may be dribbling off to the north and south).

(3) Gringauz reported Imp results of 20 to 30,000° temperatures, as contrasted with theoretical temperatures of 5,000 to 6,000°.

N67-16003

COMMISSION I

RADIO STANDARDS AND MEASUREMENTS

CHAIRMAN: DR. L. ESSEN (U.K.)

Organizational Meeting

CHAIRMAN: DR. L. ESSEN

The organizational meeting was opened by the chairman, who emphasized several points upon which action should be taken (in his estimation) during the ensuing meetings. He felt that: (1) the need existed for the establishment of a frequency standard having no recourse to time offsets for Universal Time (UT); (2) the BIPM should stop work in research on time/frequency; (3) the chairman of International Commission I should be supplied with present requirements for radio-frequency standards and that some expression should be given for future needs; (4) the Technical Committee of the IEC should study connector problems.

As the first order of business, R. W. Beatty (U.S.A.) was recognized as the reporter/editor for the Commission and proceedings at the 15th General Assembly. C. E. White (U.S.A.) was appointed assistant reporter/editor and was asked to assume responsibility for the 16th General Assembly. Prof. R. Wertheimer (France) was appointed French sessions reporter, and Mr. C. F. Pattenson (Canada) was named English sessions reporter.

Some discussion arose over the manner in which the international chairmen came into existence. It was apparent that URSI policy did not encourage quick changeover of a chairman's responsibility. Dr. Essen noted that his own British Commission desired service of a chairman (nationally) on a 3-year basis. The question was raised by member-delegates as to what policy should be applied to the International Commission. It was suggested that the chairman be elected; that a vice-chairman from a country other than the chairman's be elected; and that the chairman appoint a secretary from his own country, for more efficient cooperation.

It was proposed that the matter be implemented by having the Commission's Executive Committee choose four candidates for chairman from a list presented by the Commission delegates. On the proposal that a 3-year term for chairman be sufficient, a vote by the official delegates finally decided in favor (by a vote of 6 to 1) of two 3-year terms for the chairman, this to become effective at the time of the 16th General Assembly.

The delegates agreed that an observer from the BIPM should be invited by the President of URSI to attend the sessions of Commission I during each General Assembly. Such action was expected to expedite future movement by BIPM into the area of international comparison of precision measurements.

Standard Frequency Transmission

CHAIRMAN: DR. L. ESSEN

The first official review paper was given by Dr. J. M. Richardson (U.S.A.). It was titled "Progress in the Distribution of Standard Time and Frequency, 1963 through 1965." He pointed out that the techniques available are by vlf, lf, and hf radio propagation; by satellite relay; and by portable clocks. Both vlf and lf transmissions have provided careful long-term statistical comparison of remotely located atomic frequency standards. Precisions of at least 2 parts in 10^{11} for a 24-hr observation period is possible; also, the phase of some standard frequency transmissions is routinely steered by vlf at distances up to 5,300 km. It has been shown that the null beat between two closely spaced vlf carriers propagates stably enough to mark a particular vlf cycle. International clock synchronization by microwave impulses was carried out, using Telstar and Relay II satellites, with an accuracy of a few microseconds. Portable atomic clocks were used as transfer standards between many laboratories of the world to synchronize clocks to an accuracy of about 1 μsec.

C. Egidi (Italy) read a paper titled 'Worldwide Coordination of UT and AT." Coordinated Universal Time (UTC) is transmitted by more than 40 stations. Synchronization in times of emission of pulses is within about 1 μsec. Coordination is provided by the BIH. Several stations, following the URSI Rec. No. 1 (Tokyo), have dropped the offset from atomic frequency and some, also, for time pulses. Following URSI Rec. No. 2 (Tokyo), several laboratories have compared their time scales, both by radio transmissions and by portable atomic clocks.

A. H. Morgan (U.S.A.) reported on "A New Measurement of

Phase Velocity at vlf," which was made at the National Bureau of Standards (NBS) in 1965. The measurements were made using the signals of radio stations NPG (18.6 kHz) and WWVL (20.0 kHz). Two groups of measurements were made—one on a roughly north-south path 1,400 km long and the other on an east-west path about 2,800 km long. In both cases, the signals from the two stations were monitored continuously during the measurements in terms of a master cesium atomic standard. The reference oscillator carried along in the van was also a cesium standard and was compared with the master standard before and after each trip with the equipment van. Beyond about 2,300 km, the phase velocity, V, was found to be constant out to the limit of the measurement path, and the result was $v/c = 1-0.0026 \pm 0.0007$. This value, within the precision of the measurement, agrees with a theoretical value found by J. R. Wait and K. Spies for an experimental model of the ionosphere with a reference height of 80 km, but neglecting the earth's magnetic field.

W. Markowitz (U.S.A.) reported on some recent results concerning the dissemination and control of time and frequency by the U.S. Naval Observatory. A portable atomic clock synchronization service was begun in January 1966. The Hawaiian Loran-C chain was stabilized in the same month, using the portable clocks for initial synchronization and vlf for maintaining it. OMEGA stations provide stable frequency, controlled by cesium-beam clocks. The system will provide worldwide coverage. Cycle jumps in the Hawaii-Washington, D.C., path do not occur for OMEGA on 13.6 kHz, but do occur at 26.1 kHz from NPM. On August 6, 1966, two cesium clocks, one on the ground and one in a jet aircraft near St. Louis, Mo., were synchronized by utilizing a collision-avoidance system (McDonnell Aircraft Corp.). The air-to-ground clock difference and the side-by-side values, 30 min later, differed by 0.0 ± 0.1 μsec.

V. Kroitzsch (Germany) reported that television transmissions had been used to provide 1 μsec synchronization for distances of up to 100 km in Czechoslovakia.

J. Bonanomi (Switzerland) reported that a transmission on 75 kHz has been in operation since January 1966. The range for frequency calibration is about 1,000 km. He stated that two stations on this frequency, operating cooperatively, would provide a standard-frequency service for Europe.

B. Decaux (France) reported on the Plenary Assembly of the CCIR held in Oslo, June 22 to July 22, 1966. Resolutions were

adopted there recommending cooperation between the CCIR, URSI, IAU, IUGG, and IUPAP on the question of how best to emit both Atomic and Universal Time and frequency on the same broadcast. He described different possible systems of offset and no offset of time and frequency, in general terms. Adopting a particular system as best was considered premature at Oslo. Further study is required. He reported that the proposal to operate the Swiss station on 75 kHz to serve Europe had produced some problems in the CCIR and stated that a resolution by URSI might help.

PROGRESS IN THE DISTRIBUTION OF STANDARD TIME AND FREQUENCY

John M. Richardson (U.S.A.)

The literature from 1963 through 1965 reports results of increasing accuracy in the long-distance distribution of standard time and frequency by vlf radio transmissions, by microwave transmission via artificial satellite, and by carrying portable clocks from point to point.

Observed phase variations of vlf transmissions with length, direction, and nature of path are now well understood in terms of a mode theory of propagation. Variations with geophysical phenomena, such as ionospheric height and disturbances, have been studied sufficiently well to understand their effect on standard frequency transmissions. Both vlf and lf transmissions have been successfully used for careful long-term statistical comparison of remotely located atomic frequency standards. Results show that vlf propagation characteristics permit the comparison of remote oscillators to a precision of about 2 parts in 10^{11} for a 24-hr observation period. This property has been successfully applied to the routine steering of the phase of remote standard-frequency transmitting stations at distances up to 5,300 km.

The possibility of global distribution of standard time to microsecond resolution by vlf has been established. Phase cancellation (nulls) of two neighboring vlf frequencies will occur at the difference frequency, say 100 Hz. The fluctuation in the interval between nulls, averaged over several hours, has been experimentally found to be less than one vlf cycle at a receiving point, 1,400 km distant, even for very weak signals. Thus, the average of the nulls

may be used to identify a particular vlf cycle. Knowledge of the group delay of the nulls for the path will allow synchronization of clocks at transmitter and receiver to the resolution of the vlf cycle crossover, of the order of a microsecond. Studies are in progress to enable measurement or prediction of the group delay from vlf transmitters to any point.

Intercontinental time synchronization by microwave pulses has been accomplished from North America to Europe, via the Telstar satellite, and to Asia, via the Relay II satellite. Accuracy of the results is sent at several microseconds, with foreseeable improvement to less than 1 μsec. In principle, a transmitting clock in a satellite could be used to distribute standard time beneath its orbit. Feasibility of this system is still being established and rests on such factors as wide availability of receiving equipment, corrections for oscillator drift, Doppler effect, orbit perturbations, and propagation time.

Both vlf and satellite timing have been verified by the transportation of clocks. Portable cesium clocks have demonstrated sufficient stability on global tours to serve as transfer standards with degradation of timing accuracy of the order of a microsecond per trip. Portable quartz clocks have also been used within the United States with about the same results. Maintenance of synchronization thereafter will depend on the characteristics of the stationary standards.

New limitations on precise frequency and time measurement appear as old limitations are overcome. Studies are underway on the characteristics of oscillator fluctuations and the effect of these on phase (time) agreement, as time progresses. If frequency standards capable of stability of parts in 10^{13} or 10^{14} appear, existing methods of measurement and distribution will have to be replaced in order to enjoy the full capability of the new standards.

WORLDWIDE COORDINATION OF UT AND AT

Claudio Egidi (Italy)

At the end on 1963, four years after the UT coordination decided on and operated by MSF, WWV, and WWVH, 11 standard stations had joined the first group, by time and frequency coordinating their emissions with offset. Now, we can count more than 40 stations time coordinated, including some Loran-C networks. Because time coordination implies a maximum difference of 1 μsec, BIH measures regularly the agreement reached in practice. BIH has recently introduced the UTC and, since January 1964, has operated an important rearrangement of the Bulletin Horaire.

During these three years, another coordination, i.e., that between UT and AT, has increased its importance on account of the progress reached in the two main directions—atomic standards and Universal Time determination.

Literature on atomic standards shows that important improvements have been obtained: accuracies of 10^{-12} or better are claimed, especially for hydrogen masers. Because of the practical identification between the ET and AT scales, atomic laboratory standards can now maintain ET with high accuracy; in other words, Atomic Time observed by integration could replace astronomical determination of ET for very long intervals, such as 100 years, with an uncertainty of the order of 1 μsec.

Determination of UT, better called Terrestrial Time (TT), with PZT and astrolabe, seems at the present time to have reached its ultimate accuracy; UT2 is usually linearized through scales of atomic derivation, while the difference (AT/ET)-UT is regularly recorded. The results of astronomical observations show a noticeable decreasing for the earth's angular velocity. During 1965, it was about -200×10^{-10} = +0.7 a/y, but now it is higher (accepted international offset = -300×10^{-10}) and the peaks of the beginning of this century (about 500×10^{-10}) might be attained. Available data for this velocity allow plotting of a complete diagram for the last century, with increasing accuracy during the last decade.

UT (or TT) and AT coordination becomes, therefore, more and more important. However, Tokyo Rec. No. 1, relative to offset elimination (see DCF 77), has been followed only to a small extent, only WWVB has dropped the offset since January 1, 1965, both

for carrier and time signals, and monthly time adjustments are adopted to minimize difference to UT2. HBG broadcasts the carrier without offset but maintains the TS in agreement with UT2, so that the two signals are not synchronous.

Earth irregularities may become large enough that other stations will be obliged to eliminate the offset. But this problem, as it is interesting also to CCIR, IAU, and IUPAP, should be coordinated by the international chairman of CCIR Study Group VII. A general reconsideration has been given to the standard frequency and time services, in reply to the question: "Why do we broadcast frequency and time?" The answer is: (1) for use of laboratories comparing their linear time scales with other standards; (2) for laboratories interested in a worldwide time synchronization, in order to assess the simultaneity of an event or the progression of a phenomenon; (3) for laboratories, observatories, and mobile means interested in a precise knowledge of the TT. It is possible to meet all these requirements, and various proposals have been published. Basically, the carrier should be without offset, while two different time sequences should broadcast TT and AT independently.

Quite different is the situation of URSI Rec. No. 2 concerning the scales of AT, their origin, and their relative phase differences. This has been followed to a greater degree. The second and third points of the recommendation particularly benefit the flying clock and satellite techniques, allowing an accuracy of 1 μsec.

COMMISSION I / SESSION OF SEPTEMBER 6 (P.M.)
(JOINT SESSION WITH COMMISSION VII)

Velocity of Radio Waves

CHAIRMAN: L. ESSEN

The paper of Dr. L. Essen, "The Velocity of Light and Electromagnetic Waves," may be briefly summarized as follows:

The velocity of light, c, the frequency, and wavelength are assumed to obey the relation $c = f\,\lambda$. Heretofore, c has been obtained from frequency and distance. However, physical length measurements may not become much more precise than 10^{-8}, the present value. An alternative would be to define c as a unit, then to measure distances in terms of c and frequency (it is being assumed that frequency is measureable to higher precision, of the order of 10^{-11}). The theories of special and general relativity need to be considered in such a scheme. In this connection, the Rowland moving charge experiments and Mössbauer experiments were mentioned.

Some of the practical methods of measuring c and distance were reviewed. Using the constant C, there is equipment, e.g., the geodimeter of Vergstrand and tellurometer of Wadley, for measuring distance. The former used modulated light; the latter, modulated radio waves and, with more than one radio frequency, the stated error was ± 3 mm, $\pm 3 \times 10^{-6}$. A simple instrument, for distances up to 1.5 km, is the mekometer of Froome, using light modulated by microwaves (by means of ADP crystal). The 500-MHz microwave is frequency controlled by a cavity resonator containing dried air equalized in pressure with the atmosphere. The stated error of this method is 0.3 mm, $\pm \mathrm{I} \times 10^{-6}$. Another distance-measuring equipment (Karlolus and Helmberger) used diffraction in the ultrasound field of a liquid to measure distance, of the order of 100 m to approximately 0.05 mm, giving $c = 299{,}792.1 \pm 0.2$ km/sec.

The determination of c from calculable standards of capacitance and inductance (Rosa and Porsey) again is based on length measurements. Length measurements in the Thompson-Lampara capacitor may be quite accurate, but those for the inductor may not attain comparable accuracy at the present time.

During the discussion, some questions about relativity theory arose. The existence of the 400-m accurate baseline at Geneva was mentioned. The reduced skin effect in a superconducting cavity does not necessarily solve the uncertainty of a c measured by cavity methods. A room-temperature cavity determination of c made at the Massachsetts Institute of Technology, Cambridge, Mass., employed a range of frequencies in order to correct for skin depth.

COMMISSION I / SESSION OF SEPTEMBER 7 (A.M.)

Atomic Standards of Time

CHAIRMAN: DR. L. ESSEN

M. E. Zhabotinki (U.S.S.R.) read a paper on "Active Atomic Frequency Standards (Masers)." He reviewed the properties of ammonia, hydrogen, and rubidium masers. Respective accuracies quoted by him are 1 part in 10^{11}, 10^{12}, and 10^{12} (anticipated). The use of a He-Ne laser as a frequency standard is premature because of the difficulty of frequency conversion from optical to radio frequencies.

J. Bonanomi discussed "Passive Atomic Frequency Standards," cesium, in particular. He described properties of the recent laboratory and commercial developments, short- and long-term stabilities, and the performance achieved. The short-term stabilities of cesium (passive) and hydrogen (active) are as follows:

	Time		
Element	1 sec	1 hr	1 day
Cs	10^{-11}	3×10^{-12}	10^{-13}
$\bar{H}$	—	3×10^{-14}	2×10^{-14}

The long-term stabilities of cesium are indicated by comparisons between several Hewlett-Packard Model 5060A's. The change in the frequency difference of one pair was 3.6×10^{-13} in 31 days, and 6.3×10^{-13} in 424 days for another pair. Cesium and hydrogen have about the same long-time stability. As to reliability, the mean time between failures of the 5060A is 11,000 hr. For

60 such cesium standards tested, the mean error, or the deviation in frequency from the Hewlett-Packard reference, was 1.5×10^{-13}.

H. Berrell (U.K.) was invited to discuss the present situation of having, in effect, two units of time interval, the ephemeris second and the cesium beam (9,192,631,770 Hz). He thought that this situation should not continue. The ensuing discussion indicated that all were in agreement with this opinion. Emphasis was given to this position by W. Markowitz, who indicated that the definition of time interval given by the cesium beam is compatible with the astronomical unit of time interval. A. H. Morgan (U.S.A.) reported on a comparison of the error budgets for the cesium beam and H_2 maser with the conclusion that the latter was, surprisingly, only two times better than the former.

L. Essen read a resolution proposing that cesium be adopted to define the international unit of time interval. Considerable discussion produced two main points: (1) In view of the accuracy, experience with, and the wide availability of the cesium-beam standard, Commission I is of the opinion that it should be adopted to define the second of the Atomic Time; (2) that the adoption of cesium to define the atomic second should not preclude further researches on Atomic Time standards or on the adoption of a superior standard, when it becomes available.

PASSIVE ATOMIC FREQUENCY STANDARDS

J. Bonanomi

The first cesium-beam resonators were completed in 1965 and the first rubidium gas cells in 1958. Since these first laboratory experiments, the operation principles of passive frequency standards have not been drastically improved.

The center of the atomic spectral line, the frequency of which is located in the centimetric wave region, is the reference frequency. The spectral line is given by a transition between two hyperfine structure levels of alkaline atoms. The population of one of these levels is increased for the cesium by means of an inhomogeneous magnetic field, and for the rubidium, by optical pumping. Transitions are induced in a resonant cavity. A narrow line is produced, in the case of cesium, by selecting the cavity length and, in the case of rubidium, by using a buffer gas. Detection

means are the same as before: cesium resonance is found by the detection of an atomic beam on heated tungsten; rubidium resonance is optically detected by modifications of transparency. Finally, the electromagnetic signal inducing the transitions is produced from a quartz oscillator by frequency multiplication.

On the other hand, all these functions have been technically improved so that the 1966 accuracy is at least a hundred times better. The reliability and longevity are now noteworthy, and laboratory devices have become portable instruments.

The author describes the construction and the operation of the latest laboratory and commercial developments. Factors that affect the long- and short-term stabilities are discussed, and the review ends with a critical study of the performance achieved.

ACTIVE ATOMIC FREQUENCY STANDARDS (MASERS)

M. E. Zhabotinski

The accuracy of 2 parts in 10^{11} is attained for the molecular-beam maser with isotopic ammonia. Its essential improvement is connected with principle difficulties. The hydrogen maser has an accuracy of 1 part in 10^{12}, but we need long investigations of its aging before this figure can be confirmed. The rubidium maser has an anticipated long-term stability of 1 part in 10^{12}, but it is a secondary standard.

If the atomic-beam frequency standard accuracy is not essentially increased, the hydrogen maser will probably be selected as a primary standard of frequency (time) after its aging is eliminated. The rubidium maser will become a secondary frequency standard for general use. Molecular-beam masers will have a restricted
63 field of application, particularly as high-resolution radiospectroscopes.

The discussion of application of the He-Ne laser as a frequency standard seems to be premature because of the absence of elaborated methods of frequency conversion from the radio to the optical band.

International Comparisons and Standard Connectors

CHAIRMAN: DR. L. ESSEN

The Chairman opened the meeting and invited J. Henderson (Canada) to speak on the subject of international comparisons of standards. Dr. Henderson stated that, in addition to frequency and time, other quantities must be considered. Opinions do not always agree, but it is hoped that, as a result of the discussions to follow, more useful URSI work will evolve.

In making comparisons among nations, there are two possible approaches: obtaining scientific results or obtaining exact comparisons among national laboratories. Dr. Henderson's opinion is that URSI can perform a useful function, in either case, but he would hope that, in the future, such comparisons would more properly come under the BIPM. With regard to frequency comparisons, Dr. Henderson recommends that the International Time Bureau (Le Bureau International de l'Heure) prepare annually graphic representations of the frequency differences between the standard-frequency vlf measurements of various laboratories.

The question has been raised as to who shall participate in comparisons of standards. Dr. Henderson believes that when developments are in a preliminary stage, comparisons should not be limited to national laboratories. He realizes that this is a contentious opinion. None of this is intended to impair or restrict present comparisons of time and frequency standards. He suggests that, perhaps, the director of BIPM or his representative should be invited to attend future General Assemblies of URSI as a permanent delegate and that he receive documents of Commission I in order to facilitate coordination.

A discussion followed Dr. Henderson's remarks. It went as follows:

Guinot (France): The primary purpose of the International Time Bureau is to resolve time scales and not to compare frequencies.

Essen: A 6-month interval occurs between publications of time-scale information. Graphical representations of frequency differences would be easier to see and to use.

Selby (U.S.A.): The Chairman of Commission I does not wish to arrange such comparisons. Instead, a study group might be appointed to recommend whether proposed comparisons are actually worthwhile and to arrange comparisons.

Bourdon: It is not really necessary to appoint study groups for this purpose. However, if it were done, would the appointment be made by Commission I or by the URSI?

Henderson: It was intended that the appointment be made by Commission I.

Bussey (U.S.A.): Some comparisons can be arranged quite informally. When laboratories are in a position to perform a certain comparison, they can communicate this factor to other laboratories and, when the time is right, they can do it.

Essen: The URSI serves to get such people together so that they know when they are ready to compare.

Richardson: In this connection, perhaps some study of the entire measurement system should be undertaken, in order to see how derived quantities depend upon fundamental quantities. NBS has recently begun such a study.

Dr. Weinschel (U.S.A.) explained that, in the past, successful comparisons of standards have taken place using rectangular waveguide systems in which the waveguide joints had low reflections and were relatively trouble-free. It was more difficult in coaxial systems because coaxial connectors had more reflection, were less reliable, and were not as well standardized as waveguide joints in X-band waveguide systems. However, since 1963, improved coaxial connectors have been produced and considerable efforts toward standardization have taken place. At the last General Assembly, the URSI expressed an interest in the problem of interconnecting standards for comparison in coaxial systems.

In the area of developing high-precision coaxial connectors, the United Kingdom has worked on a connector for a 0.75-in. (DDIC) coaxial line without dielectric bead supports. In Germany, work has been done on a 21-mm connector having dielectric beads.

In the United States, a 14-mm precision connector has been developed. Mainly, the characteristic impedance has been chosen to be 50 Ω, but the values of 60, 70, and 75 Ω are also in use.

A committee to standardize high-precision coaxial connectors was formed in 1960 in the United States with representatives from various nations. It eventually became an IEEE committee and has produced a series of documents which, after appropriate review, will become IEEE standards. These documents give specifications of connector design, set limits on performance, and describe test methods that are suitable to evaluate the connectors. Proprietary rights have been waived in giving design specifications for these connectors. Two types of high-precision connectors have been defined: (1) LPC, or laboratory precision connectors having no supporting dielectric bead; and (2) GPC, or general precision connectors, which have compensated supporting beads. For highest precision, LPC is used, but most equipment has GPC. This is a new subject for the URSI, so that references in the complete paper go back to 1950, in order to bring the subject up to date. Some successful versions of high-precision coaxial connectors that meet the committee's specifications are already commercially available, such as the 14-mm General Radio connector and the 7-mm connectors available both from Rhode and Schwarz and from Amphenol. The connectors from different countries may have different joining mechanisms, but must mate when these mechanisms are removed.

Mr. Selby then called attention to his paper on the subject of international comparisons which appeared this year in the IEEE Spectrum. He showed two tables, one listing comparisons completed via the URSI and one showing comparisons in progress via the URSI.

Mr. Bourdon made a brief statement on the work of comparison of standards undertaken by the BIPM and by its consultative committee on electricity, EEC; his statement concerned two things:

1. The problem of securing international uniformity of units. In 1960, MKS units were adopted by 15 countries which passed enabling laws, and 8 other countries are now passing laws. It has even been accepted by countries, such as the United States, which do not adhere to the metric system by law. Thus, a recommendation has been introduced today for all nations to adopt this system of units.

2. The comparisons of standards of radioelectric quantities of various countries was recommended by the URSI in Tokyo in

1963. Also, the CIPM has received requests from various countries to organize a series of comparisons. After deliberation, the CIPM agreed to organize a special working group having members from 12 national laboratories and 3 international organizations. The group met for the first time in May 1965 and decided to organize a limited number of comparisons. Three comparisons are in progress and one is planned. In progress are power comparisons at 10 GHz which will include more nations.

Additional discussion took place as follows:

Selby: I have prepared a draft resolution which names several additional specific areas in which comparisons might be made.

Lundbom (Sweden): I am aware of more comparisons made during the past year than have so far been mentioned. For example, Sweden is comparing microwave power and VSWR standards with Japan and Italy. Others are attenuation and noise. What about noise comparisons under BIPM? This was not mentioned, although it is certainly possible at present.

Essen: No formal complete and up-to-date report has been prepared on comparisons of standards. The BIPM has not organized comparisons of noise standards, to date.

Richardson: The United States will introduce later a resolution incorporating field strength into the list of quantities to be compared.

Egidi: Perhaps we do not need to extend under BIPM comparisons right now, since that for power has already been delayed for a year due to various problems.

Okamura (Japan): We do not need to mention BIPM in the resolution.

Essen: It has already been deleted in the latest draft.

Mr. Lundbom introduced a further topic for possible URSI resolution. This is to encourage and set up a mechanism for URSI-sponsored comparisons among nations not having national laboratories. The proposed mechanism would involve the Chairman of Commission I forwarding requests of these nations to other nations having the required facilities. A discussion of this proposed resolution followed.

Okamura: In my opinion, the main purpose of URSI is scientific. Comparisons to give a calibration service are not necessary.

Essen: I agree, but I think that Commission I should be helpful. I do not believe that the Chairman of Commission I should

be called upon to organize all such comparisons, but he could act in an emergency. For one thing, he is not well versed in the status of all facilities at all laboratories of all nations.

Selby: This would not be an ordinary calibration service, but would be only for needful countries, and their governments would be involved, not private organizations.

Beatty: Radio science in general would benefit from agreement of measurements of all quantities by all nations. Perhaps, in the broader sense, a calibration service among nations would further scientific objectives.

Essen: Perhaps a modified form of the resolution can now be drafted, taking into account opinions expressed by official members of Commission I.

The discussion returned to the subject of coaxial connectors as follows:

Weinschel: What connector types are to be used in the BIPM-sponsored comparisons?

Selby: The 14-mm precision connectors made by the General Radio Co. will be used. Dr. Terrien will receive from NBS a number of these connectors which he can loan to participating nations not in a position to buy them.

Harris (U.K.): With regard to general precision connectors which have dielectric supports, I have proposed that the loss be represented by the contact resistance between conductors at the joining plane and that the dielectric supports be regarded as part of the coaxial line, external to the connector. This is simpler than other methods proposed for specifying characteristics of connectors.

Beatty: Bead resonance effects which have been recently observed by many will require that one regard the bead as part of the connector, at least near these resonant frequencies. There is a proximity effect, as analyzed by Dr. Bussey, which changes the frequency of resonance for one bead when another one is nearby, as in a connector pair. In the normal recommended operating frequency range of a connector, which is below these resonant frequencies, the viewpoint of Mr. Harris is quite useful.

Leonhardt (Germany): The frequency limit of connector pairs was lowered so as to avoid bead resonance effects.

Weinschel: The amount by which the frequency was lowered by the IEEE committee was decided by a majority vote. Some designs for beads were such that there would be no resonance at still higher frequencies. Why did the 1963 URSI resolution ask the IEC to select coaxial connector specifications? I believe that

we (Commission I) are better qualified than the IEC in this area. Would it be appropriate for Commission I to recommend to the BIPM that coaxial connectors be used as specified by the IEEE committee ?

Bussey: Perhaps the proposed resolution should not mention BIPM but should merely give information about the IEEE connector specifications to anyone concerned.

Blouet (France): It was decided by BIPM that the pilot laboratory for each comparison would select the connector to be used.

INTERNATIONAL COMPARISONS

J. T. Henderson

This paper discusses the role of Commission I, URSI, in future international comparisons of radio-frequency quantities, on the assumption that the present situation has not altered materially since the publication of the review articles by Selby and by Beatty in the international journal, Metrologia, for January 1966.

It is believed that the objectives of an international comparison can be set up from two somewhat different points of view, that of the scientist interested in developing new methods of measurement (among others, for such things as determining physical constants) or that of a standardizing laboratory interested in ensuring precise agreement among national laboratories so that subsequent measurements made at widely dispersed locations may be interchangeable. More often than not, individuals are concerned with both approaches because advances in either direction ultimately effect the other.

Since the last URSI General Assembly, the BIPM has undertaken the comparison of a limited number of radio-frequency quantities and, to avoid duplication, Commission I should re-examine its own position and needs. It is suggested that BIPM's position is to compare, on a periodic basis, a sufficient number of key radio-frequency quantities, the points de départ, so that national laboratories can be reasonably sure their extensions of these points, in range of magnitude, in frequency, and to other derived quantities, will accord with one another.

One would expect the URSI interest in international comparisons, on the other hand, to change through the years and that many such

comparisons under URSI auspices would be made only a few times to establish some scientific fact or numerical value that could be accepted by all. It goes without saying that the mutual interests of the URSI and BIPM require good communication of ideas and results between them.

The simplest form of international comparison is for two national laboratories to arrange common experiments between themselves and publish the results jointly. Doubtless, this will always continue. When several laboratories wish to cooperate, Commission I might well, on a more or less informal basis, arrange an orderly sequence of experiments between the parties concerned. Such arrangements would be to the advantage of all, conserving time and reducing requests to a reasonable number of quantities, for, without some prior agreement, one could imagine a chaotic state in which all national laboratories spend their whole time checking each other.

Commission I could well afford to select a "coordinator" or a "pilot laboratory" for particular tasks, following suggestions or practices of other organizations. Such a coordinator or pilot laboratory would presumably take into account the overlapping interests of other bodies and scientific unions. For example, in the particular case of radio transmissions of standard frequencies and time signals, the chairman of CCIR Study Group VII has been suggested as coordinator between CCIR, URSI, IAU, and IUPAP. The efficacy of the URSI arrangements could be reviewed at the succeeding General Assembly and modified according to the need. One would probably extend reasonable freedom of operation to the coordinator or pilot laboratory between Assemblies.

At General Assemblies, the immediate requirements for the ensuing three years for international comparison could be discussed. It is felt that a high degree of selectivity must be introduced to avoid dissipation of effort on unrewarding comparisons and, to this end, it is suggested that a wide range of magnitudes is undesirable and that conditions influencing a result, such as temperature, be rigorously prescribed to reduce the number of variables as much as possible. In some cases, the decision of Commission I might be to request the International Committee on Weights and Measures to consider undertaking additional tasks.

As an example, and to explore the opinion of other delegates, the domain of radio-frequency field strength measurement is suggested as suitable for Commission I consideration. Certainly, organizations such as ITU are concerned, so, again, we have a

case that requires cooperation with other organizations for a generally acceptable solution.

The utility of international comparisons is self-evident to some already. The author feels the "pilot" scheme, if adopted by the URSI, could extend their usefulness. No one laboratory has a monopoly on ideas or ability, as evidenced by the origin of several new techniques in recent years. Universities still continue to propose new methods, and, by the same token, some advanced industrial laboratories produce measurements of a quality comparable to any. Our task today is one of spreading information as well as one of precision comparison of results, and it is my belief, with a minimum amount of organization, the URSI can contribute much to this objective.

PROGRESS AND STANDARDS IN PRECISION COAXIAL CONNECTORS

Bruno O. Weinschel

From the end of World War II until 1963, there was no significant improvement in the coaxial connector technology in general use. Excellent work had been done on certain aspects of connector performance, particularly in England and in Germany. The English work was primarily on laboratory precision connectors (LPC) without dielectric bead support, based on the philosophy that, for highest precision, it is the province of the equipment designer to arrange the inner conductor. The German work included some advanced theory and publication of very useful design handbooks. Prior to 1963, however, this work did not manifest itself in the form of commercial availability of precision coaxial connectors, including beads.

This lack of progress was primarily due to the fact that many government specifications for connectors were of the "design type," with detailed drawings which allowed no flexibility in design. This tended to stifle the application of advanced techniques and ingenuity.

In the 1960's, two committees were formed to deal with coaxial connector standards. These were the Subcommittee on Precision Coaxial Connectors of the Technical Committee on Electronics and High Frequency Instruments of the Group on

Instrumentation and Measurements of the IEEE and American Standards Association Committee C83.2. Both committees utilized performance specifications, including interface dimensions for mating surfaces, to assure compatability of different models.

Several commercial laboratories participated in this committee work, agreeing to furnish facilities and personnel for connector tests and to forego proprietary rights in connector designs.

Spurred by the activity of these committees, rapid progress was made in the improvement of coaxial connectors. The IEEE has adopted standards for a 14-mm general precision connector which is based primarily on work done in the United States. Standards for a 7-mm general precision connector, based primarily on work done in Germany, are under consideration. The committee required that: all general precision connectors be sexless; the mating plane must be defined and include only air dielectric; no longitudinal or transverse coupling forces be permitted to displace the inner conductor when coupled; and the electrical compensation of each connector be self-contained, not relying on compensating reflections in the mating connector. All parts, including inner contact, must be captivated; however, the coupling mechanism must be detachable. The 14-mm connector is intended for use at frequencies up to approximately 8 GHz and the 7-mm connector is intended for use to 16-18 GHz.

Trial standards have also been recommended for LPC containing no bead. These are based largely upon the British work.

Spurred by these connector advances, precision techniques for measuring the characteristics of connectors and other coaxial components have advanced rapidly, so that the specifications given are realistic, not only in that they can be achieved, but also their achievement can be reliably verified. The rapidly advancing techniques include reflectometer methods, slotted-line methods, time domain reflectometry, and methods of measuring radio-frequency leakage, insertion loss, and electrical length.

Connector VSWR, loss, and nonrepeatability have long been limiting factors in the performance of many radio-frequency coaxial components. These advances in the quality and uniformity of available coaxial connectors are having a profound salutary effect upon precision coaxial components of all types.

Modern Radio Measurements

CHAIRMAN: DR. L. ESSEN

LASER MEASUREMENTS AND STANDARDS

George Birnbaum (U.S.A.)

Methods of measuring laser energy and power and methods of attenuating laser radiation were discussed in Part I. However, emphasis was given to those investigations attempting to establish standards for the measurement of power and energy. In practically all the work in Part I, the pulsed ruby laser (6943 Å) was used as the source. Part II dealt with methods for stabilizing laser frequency and wavelength, the determination of this stability, and the measurement of the absolute wavelength of stable lasers. Almost all this work was done with the cesium He-Ne laser oscillating at 0.633μ, 1.15μ, or 3.39μ. Optical standards of length and their use in length measurements were considered. This review dealt with work in the above-mentioned fields from the advent of lasers, in 1960, to 1966.

Best results on stability and resettability are for the He-Ne laser:

$$\text{Stability: } \frac{\Delta\nu}{\nu} = 10^{-10} \text{ for 8 hr}$$

$$\text{Resettability: } 2 \times 10^{-9}$$

There is a slight discordance in the measurement of the He-Ne 0.633-μ line. The most precise measurement was made by comparison with Kr 86; it is:

$$\lambda = 6329.9145 \pm 0.0002 \text{ Å}.$$

Other measurements differ in the third place after the decimal.

In the discussion, it was mentioned that the differences may be due to a drift in time, since the frequency is sensitive to gas pressure and power level. The pressure coefficient is:

$$\Delta\nu = 4 \text{ MHz/mm Hg}$$

Discussion

Gerber: Can the line width be reduced less than the line width of the cavity to approach the more favorable microwave condition?

Birnbaum: Not at the present time with the presently available techniques.

Prof. Okamura discussed in more detail the laser work in Japan, with emphasis on the microcalorimeter.

Bain (U.K.): What is the best liquid for calorimeters, copper sulfate or copper chloride? Has the volumetric method been considered? Although there is no experience at present, it is probably less sensitive.

Essen: How near are we to measuring optical frequencies by multiplication from microwave frequencies or by dividing optical frequencies? With the lack of nonlinear devices and suitable amplifiers, progress is very limited.

MEASUREMENT OF OPTICAL AND QUASI-OPTICAL WAVEGUIDES

 Dr. Rufus Fellers (U.S.A.)

Goubau's theoretical data on the loss per iteration of beam waveguides have been verified. The value is 1 dB per kilometer. New geometrical setups have been tried with success. The most promising approach appears to be to use gas lenses by introducing cool gas into a heated pipe. He mentioned experimental data on gas-filled guides with an effective focal length of 25-50 cm for 6320 Å in CO_2.

HIGH-PRECISION FREQUENCY STANDARDS - QUARTZ

E. A. Gerber (U.S.A.)

The main advances during the last three years were covered in the following fields: quartz material; theory of vibration; x-ray studies; temperature compensation; aging; precision oscillator design; and short-term stability.

There are two advances that were of particular interest: (1) the principle of containment of the vibrational energy of the main mode in the center of the plate and the attenuation of the other modes by the proper dimensioning of plate and electrodes; and (2) the improvements in the short-term stability of oscillators.

RF Measurements at Frequencies Below 1 GHz

CHAIRMAN: DR. S. OKAMURA (JAPAN)

Dr. Okamura, in the absence of Dr. Essen, acted as chairman. The first presentation, by I. A. Harris, reviewed progress in measurements of power, impedance, and attenuation at radio frequencies below 1 GHz during the past three years.

Mr. Harris noted the emphasis placed upon measurement work in the upper two thirds of the frequency range. More attention has been paid to better definitions of measurands; there is increasing use of directional couplers in comparison measurements of wattmeters.

A description of a dry-load calorimeter with coaxial input, accurate to 1 percent at levels of 100 mW, was given. A coaxial wideband calorimeter of the conventional water-flow type was described. Substitution errors from dc to rf in bolometer mounts used below 1 GHz were covered in detail by Engen's paper in 1964. Avoidance of these errors was described in two other papers.

Barlow's torque-controlled power meter was implemented by a prototype in 1966. Aida also described a method of standardizing current measurements to 1 GHz by a torque-sensitive device. Reports of international power measurements were mentioned. Also, a peak pulse measurement technique was described. Bolometer calibration capabilities of the U.S. National Bureau of Standards were extended in 1965, impedance and attenuation capabilities in 1964.

A twin-T bridge by Huntley advanced the measurement art in conductance. Techniques for measuring impedances closely resembling that of a rigid coaxial line have been developed. Much work was accomplished in the improvement of precision coaxial connectors notably in the establishment of IEEE standard specifications

for a 14-mm size. Other works relating to measurement of connector properties were mentioned. Techniques for determining large-voltage standing-wave ratios were described.

Measurement methods for properties of low-loss two-port circuit elements, three-terminal impedances using open-wire lines, and principles of a four-port directional coupler were brought out. Also described were a number of miscellaneous time-domain measurement technique improvements. Of noticeable importance has been the rise of reflectometry for coaxial measurements.

Piston attenuators were applied to wide-range precision calibrations of attenuation, with newly developed techniques.

H. E. Bussey gave the second review—progress in material measurements related to dielectric and magnetic properties. This was of greater period range than normal because of its initial appearance on a Commission I program.

In the introduction to the subject, Bussey pointed out that permittivity and permeability are relative to the free-space parameters μ_0 and ϵ_0, thereby making possible universal measurements on a defined standard substance which should agree within the uncertainties of the experiment. He then traced the development of measurement techniques from 1936 to the present day. He noted the introduction of ratio transformers for low-frequency dielectric measurements. Also mentioned were an eddy-current method useful for large complex permittivities.

A description was given of waveguide and cavity techniques of permittivity measurement, and mention was made of control of errors due to air gaps around a specimen. Intercomparison measurements conducted among the national laboratories in Canada, England, and the United States were plotted and displayed good agreement (0.2 to 0.8 percent). Finally, mention was made of the fast-changing electronic circuitry now employing deposited microcircuitry.

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A PROGRESS REVIEW OF MEASUREMENTS OF POWER, IMPEDANCE, AND ATTENUATION UP TO 1 GHz FROM 1963 TO 1966

I. A. Harris (U.K.)

A study of original work published during the past three years has revealed certain trends. First, demand for better precision and accuracy have necessitated re-examination of the definitions of the properties measured in order to take into account all the factors

that must be controlled to obtain consistency. Thus, in power and attenuation measurements, the need for clear definition has been discussed in three papers, and the effect of ordinary coaxial connectors on the results has been treated. In impedance and attenuation measurements, the modifications to definitions brought about by the introduction of precision coaxial connectors, which greatly improve accuracy, have been considered. Second, in the region below 1 GHz, where modified lumped-circuit techniques and standing-wave techniques overlap, increasing attention has been paid to the latter, sometimes extending microwave methods into the region below 1 GHz with the aim of improving accuracy. Thus, the overlap of high-frequency and microwave techniques has become more prominent. Third, the increasing use of directional couplers in the precise comparison of wattmeters is evident from several papers, while the use of two couplers with tuners connecting the wattmeters being compared, enabling advantage to be taken of precision reflectometer techniques, has also been described. A coaxial directional coupler, which is specially designed for this work, having exceptionally good directivity and inherent VSWR, has also been described recently.

New apparatus and techniques in power measurements include a dry-load calorimeter with a coaxial inlet, for use as a standard. Experimental work has been done on high-frequency power measurement by absorption of the angular momentum of a circularly polarized wave, and work on the use of ferrites for power measurement was reported. Attention was drawn to a dc-rf substitution error in double bolometer mounts. Details were published of some international comparisons of power standards at 300 and 400 MHz (U.S. to U.K. and Japan to U.K.).

New apparatus and techniques in impedance measurement include a self-calibrating twin-T bridge for precise conductance measurements, in terms of capacitance up to about 30 MHz. Impedances which differ slightly from the nominal characteristics impedance of a rigid coaxial line are of special interest, and a technique for their precise measurement (0.1 percent) was developed. Means for realizing the necessary coaxial line impedance standards were also described. Other impedance measuring techniques include a coupled sliding-termination and slotted-line probe arrangement, as well as extensions of the Weissfloch sliding short-circuit method. Special methods of measurement for precision coaxial connector-pairs were described. A resonance method, using coaxial lines, for measuring properties of low-loss two-port elements was also reported.

New apparatus and techniques in attenuation measurement include a wide-range precision calibrator, which uses a standard piston attenuator of new design; a new technique for measuring complex insertion ratio, which uses a standard piston attenuator and a standard phase-shifter in an interferometer form of circuit; and an extension of the study of modulated subcarrier methods for comparing attenuators.

INTERNATIONAL PROGRESS ON RADIO MATERIALS MEASUREMENTS

Howard E. Bussey (U.S.A.)

Measurements of the constitutive parameters in Maxwell's equations are based on electromagnetic analysis of radio circuits. The analysis takes various forms, e.g., it may involve the complex frequency of a resonator, the complex propagation constant of a transmission line, or the complex scattering of a waveguide junction, under the assumed boundary conditions.

The three years reviewed have seen increased accuracy and more advanced techniques. The modern computer allows very complicated problems to be analyzed and allows exact solution computation to be performed in place of former approximate methods. It allows the calculation of errors caused by various perturbations and the calculation of fit corrections for air gaps.

Modern techniques of power, attenuation, frequency, and phase measurement, and the use of high-precision connectors and components in coaxial and waveguide systems furnish submeasurements of high accuracy. Also, for example, at low frequencies, the ratio transformer has brought about a new generation of high accuracy, three-terminal, capacitor-type, dielectric measurements. As a result, the accuracy of dielectric measurements now tends to be limited by the departures of the specimen and the specimen holder from the ideal, assumed, mathematical description.

A recent intercomparison of dielectric measurements at three laboratories has demonstrated that the systematic errors of dielectric measurements can be approximately 0.5 percent for the real part and 0.0001 for the loss tangent.

Radio magnetic properties have become increasingly important as ferrite devices have expanded in scope. Increasingly complicated analyses of circuits containing tensor permeable material are appearing. As a result, a few measurements of exact tensor permeability continue to appear. However, the majority of magnetic measurements—for example, ferrimagnetic resonance line width, critical field for parallel pumping, saturation effects, and relaxation time—are mostly concerned with device applications. Furthermore, such measurements are of great research interest for certain fundamental processes. The permeability alone is not always the most useful quantity.

Such fundamental physical characteristics as spin-wave coupling are much measured by observing the spin-wave influence on the ferrimagnetic resonance intensity and line width. Also, spin-wave interactions in ferrite delay lines and in magnetostatic modes give further information. Another important parameter for ferrite behavior is the static quantity, saturation magnetization. These related measurements will also be reviewed.

Materials measurements in the nanowave and coherent light region will be reviewed by briefly outlining the main areas of interest.

COMMISSION I / SESSION OF SEPTEMBER 12 (P.M.)

RF Measurements at Frequencies Above 1 GHz, Including Optical Techniques

CHAIRMAN: DR. L. ESSEN

There was considerable discussion of recommendations concerning international comparison of standards and precision coaxial connectors. It was agreed that these should be referred to the meeting of official delegates for further clarification.

The chairman proposed J. McA. Steele, U.K., of the National Physical Laboratory, as English-speaking secretary and Prof. R. Wertheimer as French-speaking secretary.

Prof. S. Okamura, of the University of Tokyo, assumed the chairmanship of the meeting for the technical paper presentations. Mr. R.W. Beatty presented a "Report on Progress in the U.S.A., 1963-1966, in the Development of Radio Standards and Measurement Methods, 1 to 300 GHz." An abstract of this report follows:

REPORT ON PROGRESS IN THE U.S.A., 1963-1966, ON THE DEVELOPMENT OF RADIO STANDARDS AND MEASUREMENT METHODS, 1 TO 300 GHz

R. W. Beatty (U.S.A.)

Introduction

Developments are reported in the following fields: power, noise, reflection coefficient, phase shift, attentuation, and field strength.

Power

With regard to bolometric power measurements, the following developments were reported: evaluation of substitution error in dual-

element mounts; replacement of dual elements by a center-tapped thermistor bead; tuned reflectometer types of power meters; swept-frequency measurements of mount efficiencies; efficiency measurements at 2 and 5.4 mm; accurate calibrations of coaxial mounts with reference to standard mounts in rectangular waveguide; continued international comparisons of standards; and extension of calibration services of the National Bureau of Standards (NBS) to include WR-62, 90, 112, and 137 (153 IEC-R 70, 84, 100, and 140) waveguide (5.85-18.0 GHz), and coaxial mounts at 1, 3, and 9 GHz (GHz = 10^9 cycles per second).

Power in multimode waveguides was measured.

Short-pulse instrumentation was investigated. Pyroelectric-effect detectors, a ferroelectric bolometer, and microwave radiometers were developed for use at millimeter and submillimeter wavelengths.

Noise

Improvements were reported in waveguide mounts for gas discharge types of standard noise sources and in their calibration techniques. Extensions of NBS calibration services to include WR-90 and 137 (153 IEC-R 70 and 100) waveguide (8.2-18.0 GHz), and peak power to 1.2 GHz were accomplished. Mismatch errors in noise performance measurements were analyzed. Refrigerated microwave standard noise sources were developed, and noise sources cooled by liquid helium were calibrated.

Reflection Coefficient, Impedance

With respect to coaxial line standards, the use of air-filled lines was discussed, and a line of variable characteristic impedance was developed to calibrate time domain reflectometers.

NBS calibration services were extended to include WR 62, 90, 112, and 137 (IEC-R 70, 84, 100, and 140) waveguide (5.85-18.0 GHz), and coaxial line up to 4 GHz.

Other developments included: techniques in which a sliding load is mechanically coupled to a slotted line's probe; interchange of source and detector in slotted-line measurements; improvement of swept-frequency and tuned reflectometer techniques; and use of slotted lines and tuned reflectometers to measure reflections from connectors.

Phase Shift

The NBS standard phase shifter and measurement system in IEC-R 100 (WR-112) waveguide was described. A differential type of standard phase shifter was devised and analyzed. Automatic phase measurement systems and a technique for measuring phase modulation were described.

Attenuation, Loss

With regard to standard attenuators: true in-line coupler fixed standards were devised; additional sources of error in rotary vane attenuators were investigated; a table of attenuation versus vane angle was published; and a waveguide-below-cutoff standard was described.

Analysis of insertion loss concepts was applied to attenuation measurements. A twin-channel system was described and the modulated subcarrier method was analyzed. Methods were devised to measure small losses.

NBS calibration services were extended to include WR-28, 42, 62, 90, 112, 137, 187, and 284 (153 IEC-R 32, 48, 70, 84, 100, 140, 220, and 320) waveguide (2.6-40 GHz), and coaxial line up to 18 GHz. Attenuations of groove guides and beam waveguides were measured. Prisms were used as standard attenuators at millimeter and submillimeter wavelengths.

Field Strength, Antenna Gain

Accurate measurements were made at 4.08 GHz of the gain of standard horns. Gains of large antennas were measured. The Fresnel gain concept was examined. At 8.6 GHz, the effect of lossy earth on antenna gain was determined. Anechoic chambers were evaluated. Antenna gain was determined from measurements of scattering cross section. Modulated scatterers were used to measure field strength. Radar cross section and backscatter measurement techniques were described. Scattering cross sections of metal spheres were measured.

REPORT ON PROGRESS OUTSIDE U.S.A., 1963-1966 IN THE DEVELOPMENT OF RADIO STANDARDS AND MEASUREMENT METHODS, ABOVE 1 GHz

Sogo Okamura (Japan)

Power

A method of standard power measurement using thermoelectric cooling has been established by Sakurai et al., in the frequency range 26.5 to 40 GHz, and the error is claimed to be within ±0.25 percent. A similar method is also discussed by Heaton.

Metal film bolometers have been developed as power meters from microwave to optical frequencies. Various types of broadband bolometer units have been investigated.

General treatment of mechanical forces on materials in an electromagnetic field was made and various new proposals for the measurement of microwave power by radiation pressure have been investigated by Barlow.

Magnetoresistance effect in an intermetallic semiconductor has been applied to microwave power measurement.

Noise Source

A new method to calibrate gas discharge noise sources with a hot and a cold load has been studied and a figure of merit in calibration was proposed. International comparisons of noise sources at X-band among the United States, Sweden, and Japan has been started. Standard noise sources of cooled terminations for high-sensitivity microwave receivers have also been studied.

Impedance

Impedance standards of waveguides at microwave and millimeter wave frequencies have been studied. Automatic Smith-Chart plotters using phase directional coupler, reflection type phase shifter, or ferrite phase modulator have been investigated in the frequency ranges of 6, 11, 15, 35, and 50 GHz.

Attenuation

Standard attenuators at microwave and millimeter wave frequencies have been developed. Methods of measurement of small attenuation have been studied.

Measurement of Properties of Materials

Methods of measuring dielectric properties of low-loss materials have been made at room temperature using a high-Q resonant-cavity system, and over the temperature range of 20 to 700°C, using circular specimens and a slotted line.

A method for measurement of a plane resistor has also been studied.

New Techniques of Measurement

A high-sensitivity detector system using modulation sideband has been developed at 70 GHz and 140 GHz. Using second harmonic generators, measurement can be made with the signal-to-noise ratio of 70 dB and 65 dB at 70 GHz and 140 GHz, respectively.

Fabry-Perot resonators have been investigated in the millimeter and optical frequencies. Q factors of the resonators were measured, and values of 2×10^5 and 1×10^8 were obtained at 100 GHz and the optical frequency, respectively. Complex permittivity of various materials has been measured, using Fabry-Perot resonators at millimeter wave frequencies.

A microwave interferometer has been developed to measure small phase change. Phase angles in the range 5° to 40° have been calibrated with an accuracy to 6 percent over a frequency range of 8,080 to 11,510 MHz, and phase changes as low as 1.2° can be detected with a repeatability of 0.1°.

Discussion

Wertheimer: What method was used to obtain phase modulation?

Okamura: Modulation was obtained by use of ferrites.

Bussey: Is the low-noise Homodyne system generally applicable to other laboratory work, or is it restricted to this instance?

Okamura: Yes, it is generally applicable, but the band width is narrow.

Prof. Egidi indicated that a successful comparison of power meters and standard mismatches had been accomplished between Italy, Sweden, and the United States. (Report of Italian National Committee.)

Prof. H. M. Barlow of the University of London presented an interesting and scholarly discussion of methods of power measurement making use of radiation pressure. This can be accomplished by the measurement of linear or angular forces on absorbing or reflecting media.

Electromagnetic waves incident upon a plane interface between air and another medium (absorbing, transmitting, or reflecting) exert a force upon that medium which is proportional to the incident power level. Measurement of this force provides a means of power measurement.

An experimental wattmeter has been constructed on an angular momentum basis using an element suspended in circular waveguide operating in the TE_{11} mode with circular polarizations. A termination can be used which absorbs all the power or an element of dielectric (or a combination of dielectric and metal reflector) which is effectively one half wavelength long can be utilized. This latter element absorbs almost no power and produces torque proportional to twice the incident power, but inversely proportional to the frequency. The sensitivity of the experimental device is 90 mV/cm of deflection at a radius of 1 m. The accuracy is ±3 percent over a band width of 2 GHz at 10 GHz.

Dr. Barlow called attention to the potential advantages of using a linear system in which the force is substantially independent of frequency, as compared with an angular system in which the force is inversely proportional to frequency.

A possible system for utilizing a linear force makes use of a TE_{01} resonant cavity with a hollow dielectric cylinder inserted into the end of the cavity. The radius of the dielectric cylinder is adjusted to coincide with the maximum of the electric field in the cavity. The presence of the end of the dielectric in the standing wave within the cavity locates it in a strong gradient of stored energy. There is a linear force on the dielectric which is proportional to power density in the cavity and independent of frequency.

Discussion

Richardson: What is the precision attainable, as compared with calorimetric methods?

Barlow: Insufficient work has been done to permit evaluation. There is still a long way to go but, with more effort, knowledge, and work, radiation pressure instruments will find a place.

Okamura: Development of devices of this type in Japan have encountered problems due to mechanical shorts and vibration. Evaluation of such a power meter has provided efficiencies of 91.64 ± 0.635 percent.

Weinschel: Is this a wattmeter or a voltmeter?

Barlow: It is a wattmeter.

Richardson: By placing the radiation pressure device in a Fabry-Perot resonator, the force is multiplied by the Q of the resonator.

THE LOW-NOISE MEASUREMENT TECHNIQUE OF PENZIAS AND WILSON

W. W. Mumford (U.S.A.)

A notable advance in the state of the art of measuring low values of antenna temperatures was made at 4GHz by A. A. Penzias and R. W. Wilson of the Bell Telephone Laboratories Communications Research Division at Holmdel, N. J.[1] They used a radiometer with a low-noise (3.5° K) maser preamplifier to detect slight changes in antenna temperatures by comparison with a cold load.

The cold load was a waveguide termination completely immersed in a liquid helium bath at 4.2° K.[2] Baffles to reduce heat loss by convection and a tapered interface between the gas-filled and liquid-helium-filled waveguides were special features that contributed to its stability. Temperature-sensing diodes distributed along the waveguide between the cold termination and the flange, which was at room temperature, enabled a better estimate to be made of the noise temperature contribution due to the attenuation in the waveguide. Typically, this was ~1.0° K with a total estimated maximum error of ~0.2° K.

The cold load was used in conjunction with a variable waveguide attenuator, for calibration purposes.[3] The attenuator had a minimum loss of 0.012 dB and a maximum loss of 0.122 dB with calibration points every 0.01 dB.

An argon gas discharge noise lamp fed into the system through a 31.2-dB directional coupler was used as a reference noise source.

It was calibrated in four different ways, using the cold load, room temperature, and heated terminations as standards. The weighted means of these calibrations was $7.75 \pm 0.12^\circ$ for the noise temperature injected into the system. This was used subsequently during measurements of increments of antenna temperature, such as those related to Cassiopeia A.

Results of Background Noise

The radiometer was combined with a shielded-horn antenna whose gain and sidelobes were known accurately. The operating temperature for zenith orientation was 19° K[1] of which 6.7° K was contributed by the antenna. This was 3.5° K higher than anticipated, when all previously known or measureable sources of noise had been taken into account. The recently proposed fireball hypothesis of Dicke et al.[4] predicts about this noise temperature now for the universe. Their theory postulates a plasma at $(10)^{10}$ °K about 10^{18} sec ago, when the radius of the universe was about $(10)^{-10}$ times its present radius. The temperature is supposed to be decreasing inversely as the radius, which is increasing with time.

We might expect the temperature of a plasma in free space to be inversely proportional to its radius if its radiation pressure and its gas pressure were equal.

Results of Cassiopeia A

Measurements of the flux density of Cassiopeia A yielded $1.086(10)^{-23}$ W/sq m/Hz with a probable error of 2 percent.[3] This was based on a total of 50 drift curve observations, each approximately 40 min in duration, made on six nights in 1964. This compares favorably with numbers given by Baars et al.[5] derived from a compilation of previous measurements at a number of frequencies.

This work was done under the guidance of Mr. A. B. Crawford, Head of the Radio Research Department of the Bell Telephone Laboratories, Inc., Crawford Hill, Holmdel, N. J.

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Business Meeting

CHAIRMAN: DR. L. ESSEN

Dr. Essen opened the meeting. Dr. Egidi discussed Selby's needs for intercomparison, as previously reported. He noted Italian development of a special clock for measurement of short pulses; maximum resolution approaches 50 psec, and maximum dynamics approaches 13 μsec. Operational frequency is basically 19.53125 MHz multiplied to 1250 MHz. The reference is given in the 1966 URSI National Report from Italy on page 15, or in Alta Frequenza, 1964, pages 291 to 299.

Mr. Lundbom asked if philosophical as well as technical questions were in order. Dr. Essen replied affirmatively. Lundbom asked if the range of URSI Commission I subjects could be increased to include such subjects as digital techniques. Mr. Bussey suggested consideration of joint sessions with other commissions to determine constants of water and earth, because of the inherent international importance to radio propagation. Dr. Essen agreed that material properties, as well as precision measurements, are important to Commission I. Mr. Selby asked whether topics should be limited by reducing their scope or range or by reducing the number of topics. Dr. Essen replied that no limitations were contemplated. Prof. Wertheimer asked if there were arbitrary limitations or material agreements on topic reductions. Dr. Essen said mutual agreements were the rule. Dr. Gerber observed that standards and measurement methods for short-term stability of clocks is equally important as long-term stability. Dr. Essen agreed. He went on to say that the check of the theory of relativity with atomic clocks should be considered again. There exists some wrong conception about the execution of experiments of this kind; additionally, the

accuracy and precision of clocks have been improved enough to make these experiments really worthwhile.

Dr. Essen inquired about possible faults of the present sessions. He noted a lack of questions during several discussion periods. Mr. White noted that if papers were available as preprints on the first day of the technical sessions, discussions would be encouraged by a previous reading. Dr. Essen agreed in principle, noting that the requirement to have papers available in advance of the meetings should be rigorously enforced. Mr. Selby pointed out that review papers generally could be available well in advance of meetings, but that papers of state-of-the-art developments were hard to produce with long lead times. Mr. Bussey suggested that deep knowledge of a subject was required for a discussion period. Mr. White felt that a preview by a delegate having a physics background was sufficient to promote interest and possible questions.

Mr. Beatty inquired whether papers on radio astronomy measurements might not be conducive to joint meetings. Dr. Richardson noted that Munford's paper on noise measurements was typical of a topic lending itself to joint sessions.

Dr. Essen inquired about the scope of topics just presented and about how to enlarge the scope. Dr. Okamura suggested that topics be reclassified by measurement techniques rather than by frequency of operation. Dr. Weinschel noted that in the U.S. Commission I, an interest had developed in swept-frequency techniques. Dr. Richardson noted that some commissions had talks related to recent discoveries. Others were content with review material. It is confusing in Commission I as to what path to follow. Dr. Essen agreed that much redundancy existed in the reporting at Commission I meetings.

Dr. Essen asked whether we should have more short lively papers and fewer long review papers. Dr. Richardson mentioned that lively sessions with many short papers and sessions with carefully planned extensive review papers are mutually exclusive, to some extent. Dr. Weinschel noted that planning of research is one of the tasks of URSI Commission I, but it has never been observed.

Mr. Selby thought we should establish a list of desirable knowledge or techniques to be taken up by Commission I. Dr. Essen agreed and mentioned specifically the measurement of optical frequencies; in addition, he suggested having radio astronomy experts discuss the need for measurements in this field and alert Commission I on possibilities for research. The desirability of having working groups within Commission I was discussed by Mr. Selby and Dr. Essen. Dr. Wertheimer suggested that each national com-

mittee chairman could decide on important topics. Dr. Essen noted that two years lead time is required. Dr. Richardson stated that radio measurements do not move as fast as other fields. Time is not of great importance, as in other commissions. Guidance actions taken at these meetings are more important than time spent on new developments. Slow careful guidance of other organizations is one of the main duties of Commission I.

In closing the meeting, Dr. Essen confirmed his agreement with the viewpoints of the Commission, but he expressed the hope that young scientific people would be attracted, in spite of our conservative attitude.

OPINIONS AND RECOMMENDATIONS OF COMMISSION I

Opinion 1.1

The URSI acknowledges the cooperation of the IAU and of the CCIR in connection with standard frequency transmissions and time signals and notes the resolutions taken at Hamburg in 1964 and at Oslo in 1966. It notes also with satisfaction the interim adoption of an atomic unit of time by the CIPM in 1964. It is, however, the opinion of URSI that all the methods of operating standard frequency services that have been proposed contain defects that will cause increasing difficulties as the use of the services extends; and that these services must inevitably develop toward a system of uniform atomic time and constant frequency. This would necessitate the provision of some form of correction for those requiring astronomical time.

Opinion 1.2

The URSI welcomes the decision of the 12th General Conference of Weights and Measures empowering the International Committee of Weights and Measures to designate a quantum transition as a standard for the measurement of time and frequency.

Having considered the accuracies achieved in defining the frequencies of quantum transitions, the URSI finds that the hyperfine transitions of cesium, hydrogen, and thallium give comparable results. Although work in progress to effect further improvements may be successful, a number of years must elapse before this can be fully confirmed.

In view of the fact that cesium standards of different construction have been used and tested extensively in a number of laboratories throughout the world and found to be accurate and reliable in performance under a variety of conditions, it is the opinion of URSI that the cesium transition is the most suitable to adopt as a standard for a definition of the second.

Recommendation 1.1

Considering the importance of international standardization of units, the URSI recommends for the measurement of electrical and radio-electronic quantities the International System (SI) adopted by the General Conference of Weights and Measures (GCPM), published in Comptes-Rendus des Séances sur Poids et Mesures XI General Conference, 1961.

Recommendation 1.2

The URSI, recognizing that the full potential accuracy of atomic standards of time has not yet been realized, recommends that work in this field should be actively pursued.

Recommendation 1.3

The URSI recommends that the International Chairman of Commission I should arrange through the appropriate National Committees a meeting of the agencies responsible for the operation of standard frequency and time services in the European area with the object of discussing the best way of providing a reliable service in this area.

Recommendation 1.4

The URSI, considering:

1. the increasing interest in the international comparison of radio standards,

2. the comparisons already arranged by either the BIPM or the URSI, recommends that:

(a) the work at the BIPM should be extended particularly in respect of measurements for which well-established techniques exist,

(b) that in the interim period and in respect of new measurements and techniques, the URSI should continue to sponsor inter-

comparisons at a national level. It recommends in particular that intercomparisons of the following quantities should be carried out: field strength, attenuation, reflection coefficient, impedance, current at vhf and uhf, sinusoidal voltage at vhf and uhf, and pulsed trapezoidal peak voltage up to 1000 V,

(c) that the international Chairman of Commission I should be informed of arrangements made for such comparisons and of the results obtained,

(d) that the international Chairman of Commission I should, where appropriate, assist in effecting such arrangements and be responsible for circulating the results to National Committees and for keeping the BIPM informed of all activities in this field sponsored by URSI,

(e) that the international Chairman of Commission I be empowered to establish an *ad hoc* committee to further these intercomparisons.

Recommendation 1.5

Considering the substantial progress made in the field of precision connectors for rigid coaxial transmission lines, Commission I of the URSI recommends:

1. that for the international comparisons of radio quantities now being sponsored by the URSI, the precision connector standard of the IEEE should preferably be used.

2. that the IEC consider the adoption of the precision coaxial connector standard of the IEEE as the IEC standards for precision measurement purposes.

Resolution 1.1

Considering the common interests of the CIPM - BIPM and of the URSI (particularly of its Commission I) in the scientific and metrological aspects of various electromagnetic and other physical areas, the URSI hereby resolves to extend a standing invitation to the BIPM to appoint a representative to future General Assemblies of URSI for the purpose of mutual cooperation and benefit.

N67-16004

COMMISSION II

RADIO PROPAGATION IN NON-IONIZED MEDIA

CHAIRMAN: J. P. VOGE (France)

Organizational Meeting

CHAIRMAN: J. P. VOGE

Chairman Voge introduced Dr. Burrows (U.S.A.), who was the first Commission II Chairman. He also announced the recent election of Herbstreit (U.S.A.) to the directorship of CCIR in Geneva.

President's Report

Distribution of the President's report was promised for September 6, when official delegates would be asked for their comments. Gordon was scheduled to report on the Puerto Rico meeting held in May 1965 on planetary atmospheres and surfaces.

Election of Officers

Voge explained that he is ineligible for re-election, whereas Saxton (U.K.), Misme (France), and Herbstreit are eligible. In the past, the selection of chairman was in the hands of the Council, but this responsibility will now be shared with the commissions.

The United Kingdom has made a proposal, which is now under consideration, to elect a chairman and vice-chairman for a 3-year term, with the vice-chairman becoming chairman automatically. Burrows felt that, since this was the ultimate intent of the proposal, we should now propose a slate from which the Council may make a choice.

Misme spoke against the new proposal, saying that a 3-year term is too short. He felt we should be able to keep a man in

office for six years, if desired. If the term were to be six years, and if the vice-chairman were to be automatically moved into the chairman's position, then he might in the meantime move to another field of interest and no longer make a good Commission II Chairman. Norton (U.S.A.) felt that this difficulty could be avoided by appointing an alternate vice-chairman. Misme stated that there is no possibility of good communication between the chairman and vice-chairman, since they are usually of different nationalities. Voge felt that if the vice-chairman could not take the chairman's position, the chairman should be allowed to continue for another term. Crain (U.S.A.) asked whether the Executive Committee wanted official action or merely the opinion of Commission II. Voge indicated that it was the latter. Misme felt that it would be difficult to choose a chairman 3 years before he entered office, which is what the new proposal is, in fact, asking them to do. Voge pointed out that one of the secretaries could be from the same country as the chairman, and there could then be good contact between them. Burrows felt that there is an adequate supply of good scientists from which one could choose a chairman every three years. Crain felt that a three-year term was acceptable to the U.S. delegation. Hay (Canada) also approved for Canada, but felt that the possibility of having two or three vice-chairmen was a good one. The delegates from Finland and Germany had no official opinion on the proposal. France felt we should keep our present system. India proposed a modification to the effect that only one of the two top officers should be re-elected for a second term. The Netherlands supported the U.K. proposal. Saxton spoke unofficially, saying that the idea of having two or three vice-chairmen was a good one, and that the chairman should be eligible for re-election if desired. Sweden felt that continuity was a good idea, but had no opinion on the proposal. South Africa approved of the new proposal.

The following names were proposed for action by the Council:

Chairman: Saxton, Gordon

Vice-Chairman: Hirai (Japan), Gordon, Saxton, Grosskopf (Germany)

Secretary: English, Herbstreit; French, Misme.

Name Change

The U.S. proposal to change the name of Commission II to "Radio Propagation in Non-Ionized Media" was accepted by Commission II.

URSI-CCIR Relationship

There exists an URSI-CCIR Liaison Committee, on which Saxton is our representative. The relationship between the two organizations has not been made completely clear to some commissions but Commission II has had no difficulties. Now, especially with Herbstreit as Director of CCIR, we should experience no problems.

Resolutions

Dr. Waterman was appointed Chairman of the Resolutions Committee. Ekland (Sweden), Hirai, Misme, and Bolgiano were proposed as members of this committee. Norton asked that the resolutions be made available to the delegation a few days before the business meeting. Waterman agreed, providing there was sufficient time.

Publications

Reports of the Chairman and of the national committees, the meetings of the technical sessions, and the resolutions are published in the proceedings. The invited papers are published in monographs. The last edition took two years for publication, which is obviously too long. Methods were proposed to get earlier publication. Saxton, Atlas, and Voge will meet to consider techniques for speeding up the dissemination of this information.

Experimental Analysis of the Atmosphere

CHAIRMAN: J. P. VOGE

REFRACTOMETER STUDIES OF THE TROPOSPHERE

J. A. Lane (U.K.)

Mr. Lane summarized recent work in the development of techniques for measuring refractive index variations in the troposphere and discussed results that have been obtained with microwave refractometers on towers, balloons, and aircraft. A wide variability has been observed in the intensity, scale size, and spectral form of the refractive index fluctuations.

Stratifications in the lower troposphere are very common. Gradients of refractive index have been measured which are much greater than were previously thought likely; instantaneous differences of 5 N-units in a distance of 10 cm have been measured with spaced refractometers during a balloon ascent. However, no evidence has yet been obtained of large smooth surfaces showing changes of the order of 1 N-unit per cm, as required by reflection theory to explain angel radar echoes at wavelengths of 1 cm.

Regions of large variance in refractive index and small scale size appear to be most prevalent at the base of elevated isothermal and inversion layers—a result which tends to support the explanation of vertical-incidence layer-type radar echoes in terms of incoherent backscatter. Evidence has been obtained of wave structure in elevated layers.

There is a definite need for further work with rapid-response meteorological instruments to relate the small-scale refractive index variations with Richardson's number, wind shear, and temperature and humidity lapse rates, for example.

RADAR ANALYSIS OF THE CLEAR ATMOSPHERE—ANGELS

David Atlas (U.S.A.)

Dr. Atlas reviewed recent observations of angel phenomena with the object of reaching conclusions as to their origin and to indicate their effects on radio propagation.

Studies by Hardy et al. (1966), with high-power radars at 3, 10.7, and 71 cm have shown that "dot" angels—the strongly coherent echoes that persist and can be tracked for periods of 5 to 30 min—are explainable only if the targets are insects. Their observed cross sections, wavelength dependence, and motion relative to the mean wind are consistent with waterlike particulates having diameters of the order of 1 cm. A similar conclusion was reached from low-power vertical-incidence radar experiments conducted by Bell Telephone Laboratories and the Naval Electronics Laboratory (Crawford, 1949) and by Deam and La Grove (1965) on the basis of dual wavelength measurements and laboratory determinations of the radar cross section of insects. Experimental evidence is still lacking on the existence of refraction index boundaries sufficiently sharp and smooth to explain the dot angels, although some experiments, Chernikov (1963) and Grosskopf (1965), indicate that the scatterers have beam width and gain equivalent to a flat surface of a diameter of 1 to 3 m. Dr. Atlas feels that these experiments should be repeated.

Using the three high-power range altitude radars, Hardy et al., also observed many narrow layers of diffuse incoherent angel echoes which correlate perfectly with strata of sharp vertical refractive index gradients in the same manner as those reported by Saxton (1964) and Lane (1964). The wavelength dependence is consistent with scatter from a turbulent medium. Dr. Atlas believes these layers may be responsible for forward-scatter propagation.

The sea-breeze front is often observed, as well as mantel echoes at the boundaries of cumulus clouds. During the winter months, the tropopause was detected at wavelengths of 10.7 and 71.5 cm. Indications are that the layers are mechanically turbulent, thereby providing support for the use of both forward- and backscatter techniques for the detection of high-altitude clear air turbulence (CAT). Dr. Atlas pointed out, however, that, at present, the sensitivity of airborne radar is not sufficient to detect CAT.

Discussion

Smyth (U.S.A.) suggested that the wavelength dependence found experimentally by Chernikov and Borchardt for dot angels may be consistent with backscatter from birds, insects, and other small airborne objects. The theoretical curves for plane-wave reflection from a conducting sphere show oscillations in the resonance range of values of D/λ between 0.15 and 5. Thus, measurements at only two frequencies in this range might be expected to yield variable wavelength dependence. Atlas agreed with the statement in regard to discrete particles and stated that Chernikov's results were difficult to explain in terms of layers. The wavelength dependence computed in the Atlas paper was for layers.

Smyth made a second comment concerning the description of dot angels in terms of reflections from discrete regions where large index of refraction gradients take place. To yield an observed echo, the gradient must be coherent over a region that is large compared with the wavelength, and the normal to the flat layer must be along the direction of propagation. Computations show that the values of gradient and layer extent required to yield a discrete echo would result in ray bending of a magnitude sufficient to produce double-star images—a phenomenon never observed. Atlas said that the refractive index variations that cause twinkling of stars would give rise to the observed incoherent radar echoes.

Katz (U.S.A.) commented on some aspects of the papers by Love and Atlas. In the Wallops Island project, simultaneous radar and atmospheric data were obtained that show a one-to-one relationship between regions of clear-air echoes and disturbed refractivity. A linked mode was used which involved tracking the aircraft with one gate and sampling the clear-air echoes in a gate displaced from the aircraft by 1.5 μsec. The data show traverses through convective cells in which the echo signal strength rises and falls with the variance in refractivity. Layers that show slow wavelike undulations have also been measured in the clear atmosphere. Measurements have also been made in sea-breeze conditions. The forward sea-breeze front is usually marked by a line of clear-air echoes. On the seaward side, there are also identifiable echoes showing structure up to about 3,000 ft. At the same time, typical anomalous long-range propagation conditions were observed, with ship and cloud targets observed at ranges of 200 miles, with no evidence of extended range over land.

Bean (U.S.A.) discussed the relationship between mechanical

turbulence and refractive index variations. He observed that the strongest refractive index variations occur either when a stable layer breaks up or at transition zones.

COMMISSION II / SESSION OF SEPTEMBER 6 (P.M.)

Models of the Atmosphere

CHAIRMAN: J. P. VOGE

FINE STRUCTURE OF THE ATMOSPHERE DEDUCED FROM DIRECT OBSERVATION AND FROM TURBULENCE THEORY

R. Bolgiano (U.S.A.)

This paper consisted of a short report on the International Colloquium on the Fine-Scale Structure of the Atmosphere and Its Relation to Radio-Wave Propagation, held in Moscow in June 1965 under the auspices of the URSI-IUGG Inter-Union Committee on Radiometeorology and a summary of relevant meteorological and fluid-dynamical studies conducted during the past three years. An extended report of the Colloquium may be found in the Supplement to No. 155 of the URSI Information Bulletin.

Among the studies reported, those of velocity, temperature, and refractive-index fluctuations, made both at fixed points and by aircraft, indicated support for the $k^{-5/8}$ structure, under widely variable circumstances. They showed the plumelike connection by which warm moist air is carried aloft in unstable conditions and the tongues of warm dry air that are frequently drawn down into the turbulent layer from an overlying stably stratified zone. Laboratory experiments also supported these notions.

Theoretical models designed to explain the observed structure included the perturbing of the underside of an inversion by buoyant impacts, the creation of extensive surfaces of discontinuity by turbulent mixing in a limited zone of an otherwise continuous gradient, and a new buoyancy subrange deduction leading to a k^{-1} spectral form.

TURBULENCE AND STRUCTURE OF THE TROPOSPHERE DERIVED FROM PROPAGATION MEASUREMENTS

L. Fehlhaber and J. Grosskopf (Germany)

This paper first reviewed the beam-swinging experiments of Waterman, Koono and Hirai, and Gjessing. A correlation method developed by the authors was then described. A theoretical relation was derived between the three-dimensional correlation function of the field at small spaced antennas. Measurements were made over a 420-km path at a frequency of 1,715 MHz, with three small antennas spaced 2.5 m apart, transverse to the path. A Norton correlation function was assumed for the permittivity variations, and this function appears also in the expression for the spatial correlation function of the field.

When isotrophy was assumed and when a large number of 10-min samples were averaged, it was found that a Norton function with index 1/3 fitted the data well. This corresponds to the familiar exponent of 5/3 in the wavenumber spectrum. Individual 10-min samples yielded quite a wide scatter of index values, which was ascribed to a lack of statistical homogeneity. The measurements indicated, generally, the same scale in the horizontal and vertical directions, this being of the order of 4 m. Occasionally, the horizontal scale was some six times the vertical scale, the anisotrophy being most pronounced on days with a large average temperature between the surface and the 500-mb contour. The horizontal drift velocity was closely correlated with the cross-path wind velocity, whereas the vertical drift component was practically zero.

The theoretical method was used to predict transmission loss on paths of other lengths and at other frequencies. The agreement with direct measurement was generally good at frequencies above 1,000 MHz. At 100 MHz, the computed loss was about 15 dB greater than the measured loss. The authors concluded that partial reflections from layers play an increasingly important role at lower frequencies.

Discussion

The filtering of observed spectra, effected by the simultaneous measurement of refractive index at a pair of spaced sampling points was discussed at length by Straiton (U.S.A.), Atlas (U.S.A.),

Lane (U.K.), Katzin (U.S.A.), Bean (U.S.A.), Thompson (U.S.A.), and Bolgiano. It was concluded that this filtering is not, in fact, observed except at the low wavenumber end of the spectrum.

The question was raised by Carroll (U.S.A.) of the degree to which the recent radar backscatter data are in accord with reflections from sharp gradients, as opposed to volume scatter. Lane, Atlas, Bolgiano, Saxton, Crain (U.S.A.), and Chisholm (U.S.A.) contributed to the discussion. The large and smooth nature of the transition surface required to account for reflections was noted, as was the coherent nature to be expected of the return from such structure.

In response to a query by Kuhn (Germany) as to the possible cause of depolarization on a 3-cm line-of-sight path during nighttime fading conditions, Katzin and Crawford (U.S.A.) suggested several explanations, including ducting and ground scatter, wavy and tilted reflecting surfaces.

Atlas and Fehlhaber discussed the variation of mean-square refractivity deviations with height and concluded that the scatter propagation measurements and the radar data are in agreement.

Bull (Germany) made a short presentation of the results of his refractometer measurements on a 56-m tower in which he also found, on the average, $k^{-5/3}$ spectra. However, the exponent varied from day to day in the range of -1.2 to 2.0. He examined the dependence of the exponent on frequency range and found smaller average values (1.45) at the lower frequencies (smaller k). In addition, he observed a decrease of exponent with length of sample. He studied anisotrophy of refractive index structure, finding smaller vertical than along-wind scales (ratio 0.75) at all scales and smaller cross-wind than along-wind scales (ratio 0.50) at large scales (50 m), but near isotrophy at smaller scales (10 m).

Gjessing also reported on some recent measurements of temperature structure up to 8 km that he believes should indicate an increasing scatter cross section with altitude. Inasmuch as experimental studies show a decreasing cross section, he concludes that temperature is not an important factor in this height interval.

Misme asked if a single spectrum could adequately represent the entire common volume on a forward scatter path. To this, Atlas replied that he feels most of the energy is scattered from thin (30- to 100-m) layers, and that he believes the spectra in these layers will exhibit the $k^{-5/3}$ form and differ only in intensity. There was lively discussion of this point by many of those present, but no firm conclusion was reached.

Theoretical and Experimental Investigation of Propagation in Nonionized Media

CHAIRMAN: J. P. VOGE

THE INFLUENCE OF TERRAIN IRREGULARITIES ON THE PROPAGATION AND REFLECTION OF RADIO WAVES

J. B. Smyth (U.S.A.)

Dr. Smyth first stressed the failure of the Kirchoff-Huygens (K-H) theory in the terrain-scattering problem. This was illustrated by reference to the measurements of radiation patterns from electromagnetic horns by Barrow and Greene. Using measured distributions of E and H across the aperture and calculating the far-field pattern therefrom by the K-H theory, good agreement was found for the main lobe, but very poor agreement was found for the side lobes. Schelkunoff pointed out that part of the difficulty was due to integration over only part of the total surface, instead of over a closed surface, as required by the K-H theory; as a result, the solution obtained does not satisfy Maxwell's equations.

In terrain scattering, the problem is analogous to that encountered in the horn-radiation problem, in that one is dealing with the side lobes rather than the main lobe.

The summary of sea and terrain clutter observation of I. Katz was reviewed. The variation with frequency led to the concept of radar color as a function of the depression angle of the illumination. As an example, the City of Chicago appears to be almost colorless in radar terms.

Depolarization of the field, due to reflection from an irregular surface, was discussed. The measurements of the cross-polarized

component at 1 GHz by Blomquist showed that it varied from -20 dB for flat terrain, to -10 dB for mountainous terrain.

The observations on reflections from the moon were also discussed. It was pointed out that, both on optical and radio frequencies, the observed reflections are about one twentieth that expected from a perfectly reflecting surface. This result has led to attempts to deduce the dielectric properties and statrification of the moon's surface.

Discussion

R. K. Moore (U.S.A.), in a discussion of some length, stressed the importance of depolarization (i.e., cross polarization) in terrain scattering. He referred to a recent paper by A. K. Fung in which calculations of this quantity were made. Moore illustrated the importance of the cross-polarized backscatter by radar photos taken with a side-looking, K-band radar of narrow beam width, with independent recording of the like (horizontal) and cross (vertical) polarized components. The cross-polarized component showed great detail and contrast in those regions where the surface was rough.

Smyth referred to a paper by J. J. Martin (mentioned in his written paper), in which hf ionospheric backscatter was explained in terms of facets. Smyth criticized this on the basis that:
(1) strong radar returns were obtained from Kansas to California, whereas statistical characteristics of the surface given by Hayre and Moore would give almost no facets of suitable slope for Kansas and a large number for the Rocky Mountains; and (2) on hf backscatter, one cannot distinguish land from sea.

J. H. Chisholm mentioned polarization rotation by the ionosphere as possibly being of importance in this type of observation.

R. K. Moore stated that absorption by the ionosphere needed to be taken into account.

M. Katzin offered an explanation of the failure to distinguish between land and sea on hf ionospheric backscatter. For sea return, the angular distribution of backscatter coefficient shows a strong peak at vertical incidence, a slowly decreasing value at intermediate angles, between about 60° and 5°, and a further dropoff below 5°. On the other hand, for land return, the angular distribution is relatively flat over the whole range, from 90° to, perhaps 5°. The land and sea return amplitudes are not

greatly different, in general, in the intermediate angular range that would apply to observation of backscatter.

U. Kühn reported on some measurements made at 1 GHz over a 5-km path, in which circular polarization was employed. With snow on the ground, the reflection coefficient (determined by measuring the interference pattern with height) was 0.95. With a growth of corn in the reflection region, the reflection coefficient was 0.55 while, when a forest intervened, there was only 2 to 3 dB between maximum and minumum in the interference pattern.

C. I. Beard (U.S.A.) showed data taken under controlled conditions in a ripple tank, which showed that non-plane-wave illumination of the reflecting surface was of importance, and should be taken into account.

P. Misme reported the results of some measurements made of an optical path over the Mediterranean. Observations were made of sunlight reflected from the sea as the sun rose and set. It was found that the rate of change of intensity of light reflected from the surface was maximum at an angle (α_{max}) which was displaced from the angle of specular reflection or reflections. In an attempt to explain this, a facet model was used, with facets distributed over a range of slopes. In one model, a uniform distribution of slopes was used; in another, a Gaussian distribution. The effective reflection coefficient (albedo) found to be suitable was 10 percent. The shift $\alpha = s - \alpha_{max}$ was found to be a function of maximum surface slope, whereas the reflection coefficient was a function of the albedo.

DIVERSITY DISTANCES AND LOSS IN PATH ANTENNA GAIN IN TROPOSPHERIC, BEYOND-THE-HORIZON PROPAGATION

109 D. M. Hirai (Tokyo)

Dr. Hirai summarized his work and that of other authors on the antenna separation needed for diversity, and on the loss in effective antenna gain on tropospheric beyond-the-horizon paths. Both broad-beam and narrow-beam antennas were considered, and an extensive bibliography is given in his paper.

The theoretical results on diversity distance differ by as much as 4 to 1, because the various authors used different scatter models. In addition, the diversity distance seems to depend on the beam width of the antenna.

In regard to the loss in effective antenna gain, Hirai compared: (1) the estimates from several workers on a single chart as a function of the ratio of the scattering angle to the antenna beamwidth (Θ/Ψ). To a first approximation, the spread between the various methods corresponds to a change of less than 3 to 1 in the ratio (Θ/Ψ). In every case, the estimated loss increases with increasing distance. While these models "explain" most of the data available measurements at very long and short distances do not seem to fit this model.

Discussion

Chisholm summarized the results of an extensive earlier experiment with three sets of antennas at several different distances. He pointed out that these results, particularly on the longest path, cannot be explained by any function for which the ratio of angles (Θ/Ψ) is the only variable. In particular, the measurements indicate that the mechanism contains a frequency-dependent factor which seems to be ignored in the theories.

Boithias (France) summarized several French experiments and reached the conclusion that a plot of loss in effective antenna gain showed less scatter as a function of the gain G than as a function of the ratio of angles (Θ/Ψ). Two sets of data did not fit the curve of L versus G: one small sample at relatively short distances and the Chisholm data at 400 mc and 600 miles.

Bullington (U.S.A.) pointed out that the concept of reflections from an exponential atmosphere tends to explain the available data on loss in effective antenna gain at all distances.

On this model, the path antenna degradation factor is $10\log\left[1 - e^{-0.14\,(y_2-y_1)}\right]$, where (y_2-y_1) is the difference in elevation, in kilometers, between the top and bottom of the common volume.

De Bettencourt (U.S.A.) urged that correlation bandwidth measurements be made simultaneously with signal level measurements, so that the coupling loss and estimates thereof might be better understood. Bandwidth degradation and coupling loss are both the result of multipath transmission, in either the turbulent scatter or multilayer models. The statistical distributions of bandwidth and coupling loss should be studied, particularly at low outage time percentages.

Waterman (U.S.A.) commented that, with respect to lateral spaced-receiver correlations under two different configurations—parallel transmission paths and crossed transmission paths—Dr. Hirai had pointed out that the correlation is higher on the latter. Waterman mentioned that, if an appropriate time lag is introduced, the correlation on the former can be raised, under some circumstances.

Waterman also pointed out that the empirical curve of loss in path antenna gain, as a function of antenna size, as obtained by Yeh and reproduced in Hirai's talk, was incorrectly obtained, in that Yeh had misused some of the empirical data from which the curve was constructed.

Finally, Waterman expressed his opinion that Hirai had performed an excellent and thorough survey of a difficult and confusing topic.

Effects of Propagation on the Measurements of Distance, Angle-of-Arrival, and Doppler Effect

CHAIRMAN: J. P. VOGE

THE EFFECTS OF PROPAGATION ON MEASUREMENTS OF DISTANCE, ANGLE-OF-ARRIVAL, AND DOPPLER EFFECT IN GROUND-TO-GROUND SYSTEMS

M. C. Thompson, Jr. (U.S.A.)

The effects of variable propagation velocity on measurements involving transit time were discussed. Applications to distance, angle, and Doppler measurements were considered for paths within the lower 5 km of the atmosphere. Progress during the past 3 years was reviewed and current work and plans were described.

Discussion

Following the presentation, there were questions seeking clarification of some of the slides which showed data of angle-of-arrival and range variations obtained on various test paths.

EFFECTS OF PROPAGATION ON THE MEASUREMENTS OF DISTANCE, ANGLE-OF-ARRIVAL, AND DOPPLER EFFECT IN EARTH - SPACE LINKS

J. Ranzi (Italy)

Dr. Ranzi pointed out that there were not, at present, experimental methods for a direct determination of the error introduced by

the tropospheric propagation in the measurement of the distance between an earth station and a station in space. He reported that distance errors had been computed for different elevation angles for assumed atmospheric refractive index profiles. Fluctuations in the range errors have also been computed for assumed atmospheric inhomogeneities.

Ranzi reported that the influence of the troposphere on baseline tracking systems has not been determined experimentally. The only experimental results available refer to ground-to-ground links; however, owing to the strong influence of the lower troposphere in the determination of target range, ground-to-ground measurements may be useful.

In determining the effect of the troposphere on the angle-of-arrival of space signals, very little increase in accuracy was obtained by using on-site radiosonde profiles instead of the CRPL standard atmosphere radio refractive index profile. Some researches reported using radiosonde data for the first 10 km and the CRPL reference atmosphere for greater heights. A new method of computing the elevation angle error, using the mathematics of earthquake seismology, was reported. A computer method was also reported that used an exponential model of the atmosphere and yielded the elevation angle error as a function of surface refractivity. Curves were presented giving the elevation angle error as a function of apparent elevation angle for some atmospheric models.

Ranzi reported that the error in the Doppler frequency can be computed, once the error in the elevation angle is determined by one of the methods available today.

Discussion

Gerks (U.S.A.) described a 230-km propagation link over U.S. Midwest terrain, operating near 1,000 MHz, and designed so that the phase variations of the received cw signal can be recorded. Typically, the phase meter covered a range of 17 π radians without resetting, which occurs automatically. The system employs a coherent transponder at one terminal, so that phase fluctuations on a round trip can be measured at one terminal. Thus, oscillator drift does not affect the results.

Slides were used to demonstrate amplitude and phase variations, first with airplane scattering, then with several cases of atmosphere stability, ranging from a strong duct to fully developed turbulent scatter. These showed remarkable phase stability under

superrefractive conditions, even when large amplitude excursions were present. Under scatter conditions, the phase record showed pronounced random fluctuations of short period, as well as slow prolonged drift in one direction. It was pointed out that the phase record cannot be used as an indication of path-length variations when fully turbulent conditions exist, apparently because of ambiguity of the phase shift occurring during deep fades. It was suggested that the phase record may be more indicative of layer reflections than the amplitude record.

As a supplement to the material presented by Thompson and by Ranzi, Waterman presented the results of a line-of-sight propagation experiment at 35 GHz. In this experiment, a narrow beam cw signal was transmitted over a 26-km path having completely negligible ground reflection. The receiving antenna consisted of eight individual 1-ft diameter parabolic reflectors with horn feed. Amplitude and phase of the arriving wave were measured and recorded separately from each of the eight individual elements. Sample results were shown of the amplitude at each element, as a function of time, a noteworthy feature being the frequent occurrence of a small (1 dB or so) perturbation at one antenna element, which subsequently appeared in succession at each element across the entire extent of the array. Similar phenomena were observed in phase differences between successive elements, the extent of the perturbations being generally several tens of degrees of phase. A slide was also shown of the consequences of a computer analysis, in which the basic amplitude and phase information was processed so as to indicate the response of the receiving antenna, when the antenna was treated as a conventional scanning phased array. Angular fluctuations of a few tens of arc seconds were apparent. Finally, a motion picture was shown displaying, first, the amplitude at all eight antenna elements and, second, the phase (relative to a reference in the center of the array) at all eight elements.

Katzin, noting that Dr. Ranzi had referred to the use of the CRPL standard atmospheric radio refraction profile sample as a prediction method for range errors, said that they have been making meteorological measurements in the Cape Kennedy region for the purpose of developing improved corrections. Radiosonde, wiresonde, airborne refractometer, and calibrated hygrothermographs are used in connection with an interferometer network having 100,000-ft baselines. Calculations of delay, using the measured profile and the CRPL method based on the ground-level value of refractivity, show significant differences between the two methods. Furthermore,

appreciable horizontal differences in refractivity are found to occur between the various stations of the interferometer system. It is believed, therefore, that significant improvement in the calculation of range errors and range rate errors can be accomplished by using the actual measured profile and by incorporating the effect of non-horizontal stratifications.

In response to a question by Dr. Lane regarding the application of theoretical analyses to propagation experiments, Dr. Waterman presented a slide showing measured values of the correlation between the postdetection signals received simultaneously at two receiving antennas separated horizontally and transverse to the propagation path. The radio frequency was 35 GHz and the line-of-sight path length was 26 km. The slide showed correlation as a function of antenna separation. Superimposed on the measured data points was a curve computed theoretically by Tatarski. This figure was presented as an example in which one particular theoretical development was compared with measured data.

At the invitation of Chairman Voge, Waterman presented recent data on the simultaneous propagation of cw and optical waves through the same portion of atmosphere. A 3-GHz source was used at the transmitting terminus and was split into two channels. One channel was propagated directly over a 200-m path to the receiving site. The other channel was used to modulate a helium - neon laser beam, and the modulated light beam was propagated simultaneously over the same path. At the receiving terminus, the 3-GHz modulation was removed from the light beam and was compared, in phase, with the direct 3-GHz transmission. Since the 3-GHz transmission is strongly affected by the presence of water vapor in the atmosphere, while the optical transmission is not, the phase difference so obtained gives a measure of the integrated water-vapor content along the path. Examples were shown in which the measured phase differences were compared with those computed from meteorological measurements made at one point, there being a general overall, but not a detailed, agreement. A sample of the detailed fluctuations was then shown.

Propagation and Radiometry for Millimeter and Submillimeter Wavelengths

CHAIRMAN: J. P. VOGE

This session consisted of two distinct parts with no overlap in the basic presentations or in the discussions. The report of the session is divided accordingly.

PART ONE

INFRARED RADIATION, ITS MEASUREMENT AND APPLICATION IN THE PHYSICS OF THE ATMOSPHERE

F. Möller (Germany)

Dr. Möller presented a survey paper on the techniques and uses of submillimeter wavelengths. He divided his talk into two parts: (1) the properties of solar infrared radiation; and (2) the properties of terrestrial infrared radiation.

For the solar radiation, Dr. Möller noted that only the short wavelengths could be measured at the earth's surface, and he discussed the spectral absorption characteristics of the various constituents of the atmosphere. He proposed a satellite experiment in which the transmission characteristics of the solar radiation through upper layers of the atmosphere could be measured to obtain information on the extent to which these gases are present in these outer layers.

Dr. Möller reviewed some of the materials that might be used as detectors for the measurement of infrared radiation and presented data on the wavelength dependence of the sensitivity of these materials.

Terrestrial radiation from the surface of the earth was considered as a means of studying topographic features of the earth. These studies would need to be limited to windows, for satellite type measurements, but could be used over a broad frequency spectrum for observations near the surface.

Radiation from atmospheric gases, as would be received in a satellite, was discussed, and it was noted that various depths into the atmosphere could be examined by the proper selection of frequencies. The possibility of determining the vertical profile of temperatures from a series of measurements at various wavelengths, or at various nadir angles, was noted.

Discussion

Dr. Carroll (U.S.A.) described a transhorizon propagation measurement by Curcio and Drummeter of the U.S. Naval Research Laboratory and compared the attenuation rate with that measured at various radio wavelengths. He asserted that these data showed that the same mechanism for transhorizon propagation was applicable to optical and radio waves and that the attenuation rates were in agreement with that calculated by him for various models of the atmosphere.

PART TWO

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A. Robert (France)

Dr. Robert presented a summary paper on millimeter radio waves and their study by radiometry. He suggested as possible applications of the use of millimeter-wave radiometry: (1) the measurement of the temperature and water-vapor density profiles of the atmosphere; (2) the study of the planets and their atmospheres; (3) the study of surface topography; (4) the determination of

fusion temperatures of metal; and (5) the distinction between various earth surface materials.

Dr. Robert (France) presented a curve of water vapor and oxygen attenuation near the earth's surface based on the early constants given by Van Vleck and Weisskopf. He then discussed the reradiation by the atmospheric gases and the transmission of this reradiation through the atmosphere.

The thermal radiation from objects at various temperatures, in accordance with the Rayleigh-Jean approximation of Planck's law, was mentioned. Solar radiation data from a number of references was cited as an example of thermal radiation at millimeter wavelengths.

The speaker pointed out the distinction between blackbody radiation and reflection from surfaces. He indicated that reflectors will appear cool and blackbody radiators warm.

The use of millimeter waves for the measurement of the distribution of water vapor and temperature with height was stressed as one of the more promising meteorological applications.

Several other possible uses of millimeter waves were noted, including the measurement of velocity at great heights by the use of the Doppler shift of the radiation lines, as observed in a moving vehicle.

Discussion

Dr. Straiton commented on three of the applications proposed by Dr. Robert, as follows:

1. The temperatures of reflecting surfaces will be functions of the part of the sky reflected by them. Horizontal surfaces may appear quite cold while tilted, or rough surfaces may appear much warmer.

2. Recent measurements of the temperature profile by angular scans have been made at the University of Texas, which show crude agreement with radiosonde measurements. Background noise, the need for finite bandwidth, and changes in the atmosphere during the measurements made the method somewhat questionable as a practical operating scheme.

3. Whereas the sun is basically a thermal radiator, nonthermal radiation has been observed during eclipses. With antennas capable of looking at spots on the sun, it is possible to detect sun spots in the early phase of their build-up.

Dr. Tukizi (Japan) described a diffraction experiment made over a circular arc at a frequency of 48.6 GHz. Beyond the horizon, conditions were simulated by having a transmitter a few inches above the curved surface. The receiver was kept a short distance above the survace and moved around the arc to distances of tens of meters. These measurements were made over a dielectric surface and over a metallic mesh surface. The results for both polarizations were compared with calculations, with satisfactory agreement.

Dr. Misme (France) noted that, in the measurement of 5-mm propagation through fog over a 600-m path, the attenuation on vertical polarization was less than for horizontal polarization. In another experiment, he found that this same discrepancy existed for ranges of 60 m to 1,000 m. The difference was 3 dB, at the shorter distance, and decreased to zero, at the greater distance. No explanation was forthcoming. Dr. Misme noted that this difference did not exist in rain.

Dr. Lane (U.K.) showed signal strength recordings at 2.9 mm over a 150-m path using a reflector for two-way transmission. Daytime scintillations were more intense than after-dark values. Dr. Lane suggested this as a tool for studying meteorological variations of refractive index.

COMMISSION II AND COMMISSION V / JOINT
SESSION OF SEPTEMBER 12 (A.M.)

Planetary Radio and Radar Astronomical Observations

CHAIRMAN: J. P. VOGE

The meeting began with two invited papers. The first, by Dr. C.H. Mayer (U.S.A.), consisted of a review of the radiometric studies of the planets conducted since the last General Assembly. The second invited paper was on the subject of radar astronomy and was given by Dr. G. H. Pettengill (U.S.A.). Short contributions were then read by a number of authors.

RADIOMETRIC STUDIES OF THE PLANETS

C. H. Mayer (U.S.A.)

Observations of Mercury by Kellermann at Parkes, at $\lambda = 11$ cm, indicate either a uniform surface temperature of 300° K or a temperature that varies with the position of the subearth point, with respect to the subsolar point as $250 + 260 \cos^{1/4} \theta$ °K. These values support the determination of Howard et al., at Michigan some three years ago. Radar results show that Mercury does not rotate synchronously with respect to the sun. Thus, the conclusion that the temperature at the subsolar point must be very high (1,100°) reached by Howard et al., is no longer tenable. Observations at very short wavelengths ($\lambda = 8$ mm by Salomanovich and $\lambda = 3$ mm by Epstein) should be expected to show phase variations in temperature (as observed for the moon), but the results are a little uncertain, at present.

An extensive series of interferometer observations of Venus by Clarke and Kuzmin at the 9.6-cm wavelength indicated that the emitting agency is the surface and that the dielectric constant is 1.C. = 2.5. A number of observations of the brightness temperature of Venus have recently been made in the wavelength range $20 \text{ cm} \leq \lambda \leq 100 \text{ cm}$ and indicate a decline in temperature with increasing wavelength. It is supposed that this is a consequence of a change in the surface emissivity.

A search for a water-vapor absorption line at 1.35 cm has been made at M.I.T. by Staelin and Barrett. The results, in 1964, gave weak evidence for the existence of such a line, but better observations in 1966 are definitely negative.

Mars has been observed at a number of wavelengths in the range $0.2 \leq \lambda \leq 20$ cm. Much of this activity was stimulated by the publication of what now appears to be a spurious result. The average temperature seems to be of the order of 250° K, with no evidence for a wavelength dependence, i.e., no nonthermal emission.

The most important new result for Jupiter concerns the dekameter burst emission. As has long been known, this is most probable when certain Jovian longitudes (110° and 150°) face the earth. This behavior is attributed to the eccentricity of the Jovian magnetic field. Warwick has shown that additional control appears to be exerted by the satellite Io. It seems that the radiation can be expected when one of the above longitudes is facing the earth and Io is entering or leaving the Jovian magnetosphere, which like the earth's is presumed to have a shock front formed by the pressure of the solar wind.

In the case of Saturn, early measurements of polarization of the measurements have not been confirmed in more recent studies by Davies et al. or by Kellermann. On the other hand, the apparent temperature increases from about 100° K at 3 cm to about 250° K at $\lambda = 18$ cm, indicating that perhaps part of the emission is nonthermal or, alternatively, that the temperature of the atmosphere increases with depth.

Uranus has been observed at 11 cm by Kellermann at Parkes (130°K) and Uranus and Neptune at 1.9 cm, using the Greenbank 140-ft dish. The temperatures were 220°K and 180°K, respectively. Dr. Mayer suggested that these might be fixed by the emission occurring at the height in the atmosphere at which ammonia freezes.

RADAR ASTRONOMY

G. H. Pettengill

Dr. Pettengill discussed, first, the radar observations of the planets (notably Venus and Mercury), that are contributing to our knowledge of the elements of the orbits of the planets and the size of the solar system. Four groups, namely, Cornell University (Arecibo), Jet Propulsion Laboratory (JPL) (Goldstone), Lincoln Laboratory (Millstone), and the U.S.S.R. Deep Space Tracking Station (Crimea), have reported flight-time determinations to Venus with an accuracy approaching or equal to $\pm 10\,\mu$sec. At a distance of 1 Astronomical Unit (AU), this represents a fractional accuracy of 6×10^{-9}. The Doppler shift of the echoes (and, hence, the velocity of the planet with respect to the earth) can also be determined with precision; but here the fractional accuracy is only 5×10^{-7} at best (and considerably worse than this when the Doppler shift becomes small near inferior conjunction). Based primarily upon all past radar flight-time measurements at Arecibo and Millstone, together with all optical observations at NRL since 1950, Shapiro and his co-workers at Lincoln Laboratory have been able to redetermine the elements of the orbits of earth, Venus, and Mercury, together with the radii of Venus and Mercury, and the values of the AU and earth/moon mass ratio. In all, 23 parameters were relaxed and a least-mean-square solution obtained for two possible physical universes. In one, it was presumed that the dictates of Newtonian mechanics hold, and, in the other, that Einstein's general relativity applies. The observations are not yet adequate to permit one to choose between these two systems, but they are expected to do so in the course of a few years. Below are some of the results.

Element	Pre-radar Value	Newtonian Universe	Gen. Relativity Universe	Formal Error
AU	–	499.004778 sec	499.004782 sec	±0.000005 sec
Venus radius	6,100 km	6,055 km	6,055 km	±1.1 km
Mercury radius	2,420 km	2,433 km	2,436 km	±2.2 km
Earth/moon mass ratio	81.30 ± 0.01	81.3024	81.3030	±0.005

Dr. Pettengill pointed out that the formal errors do not include possible systematic errors, and these cannot be estimated. Yet, he doubted that the errors were larger than five times the formal errors given.

Observations of the reflection properties of Venus were described next. The radar cross section of Venus has a value of about 20 percent of the physical area of the disk (πa^2) at long wavelengths ($\lambda \geq 6$m), and falls to 15 percent at 70 cm, 11 percent at 12.5 cm, and 1 percent at 3.8 cm. This rapid drop with decreasing wavelength is not observed for the moon or for Mercury, and is the subject of a separate paper by Evans given later in the session. Fluctuations of cross section of ±50 percent are observed at Arecibo (λ = 70 cm) and elsewhere. These are attributed to changes in the nature of the terrain at the subradar point—the point from which most of the echo energy is returned. At 3.8 cm, much larger fluctuations are observed, for example, increases of as much as 300 percent, and these will be discussed by Evans.

The angular scattering law for Venus has been determined at a number of wavelengths. When compared with the law for the moon, it is found that the echo power falls off, initially, more rapidly with off-perpendicular angle, for an elemental area of the surface of Venus, than for a corresponding element on the moon's surface. This is interpreted to mean that the rms slope of the surface, over intervals that are large, compared with the wavelength (for example, ~ 10 λ or more), is less for Venus than for the moon. (Values obtained are 8° for Venus and 12° for the moon for λ = 23 cm.) At large, off-perpendicular angles, both surfaces contribute more reflected power than can be associated with this quasi-specular scattering. This is attributed to the presence of some structural elements having approximately the same size as the wavelength. However, the number of such elements appears to be smaller for Venus than for the moon.

In the case of Mercury, the cross section has been determined at five wavelengths in the range of 3.8 cm $\leq \lambda \leq$ 70 cm and found to be 5 to 6 percent of the projected area of the disk. The angular scattering law is well known only at one wavelength (70 cm), and appears similar to the moon's. In view of both this and the similarity in cross sections, Dr. Pettengill wondered if the surfaces of Mercury and the moon might not be very similar.

Mars has been extensively studied only at Arecibo (λ = 70 cm) and Goldstone (λ = 12.5 cm). The average cross section is of the order of 8 percent, but values as low as 4 percent and as high as

14 percent are observed to repeat at given Martian longitudes. There is a good correspondence between the two sets of measurements, and general agreement that the strongest reflections appear to be associated with visual dark features (for example, Syrtis Major). The angular scattering law for Mars has not yet been determined.

Two claims of Jupiter echoes have appeared in the literature. The JPL group, in 1965, failed to repeat their detection, suggesting that the first detection (if valid) resulted from some transitory reflection phenomenon. At Arecibo, extensive observations were made in 1964 and 1965, but without success. An upper limit for the cross section at λ = 70 cm, derived from this work, is $\sigma \leq 0.5$ percent.

Dr. Pettengill concluded by describing the work that has been performed to determine the rotation rates of Venus and Mercury. Using the delay-Doppler mapping technique, a period of 245.1 ± 2 days and pole position RA = 90.3 ± 1°, δ = -66.7 ± 1° have been obtained for Venus. The measurements were made at the Arecibo Ionospheric Observatory, and their reduction was performed at the Lincoln Laboratory by Dr. Shapiro and his co-workers. Dr. Pettengill stated that this pole position (1950 epoch) implies that the Venus pole is inclined to the plane of the earth's orbit by 89.8 ± 1°. That is, there seems to be an effect of the earth on the position of the pole of Venus.

A second method of determining the rotation rate has been applied to Venus by Carpenter and Goldstein at the JPL. This method depends upon identifying the anomalously reflecting portions of the surface (there are a number) at successive inferior conjunctions. So far, features have been recognized in three successive inferior conjunctions, and a period of 244 ± 1 days obtained. This value is very close to the period 243.16 days required to cause Venus to face the earth in precisely the same way at successive inferior conjunctions, i.e., synchronous to the earth. According to a number of theoretical estimates, it seems difficult to understand how this can be brought about, though it is generally agreed that the chances would be improved if Venus had, initially, a retrograde rotation, but with a somewhat longer period in the past than now.

In the case of Mercury, delay-Doppler mapping measurements at Arecibo have shown that the rotation is direct, with a period of 59 ± 3 days, and is not synchronous (88 days), as had previously been supposed. A re-examination of the telescopic evidence has confirmed that this period was quite consistent with optical observations and is, indeed, demanded by it, according to one authority. It appears that Mercury executes 3/2 axial rotations in every

complete trip around the sun. Thus, it presents alternate faces to the sun at each perihelion passage. The period should, therefore, be 2/3 × 88 days = 58.65 days in good agreement with the radar results. Reasons for this form of resonant trapping have been worked out and seem well understood. If Mercury is slightly elliptical in shape, it will become oriented with its semimajor axis pointing toward the sun during perihelion passage due to the gravitational couple, which is strongest there. However, the orbital angular velocity is greatest at perihelion passage (Kepler's third law), so the sun tries to set Mercury spinning faster than synchronously. The net result is that capture with 3/2 rotations between perihelion passages is extremely likely.

Short Contributions

J.E.B. Ponsonby (U.K.): An experiment has been carried out jointly with the U.S.S.R. Deep Space Tracking Station to study Venus with a bistatic radar. The Crimea station acted as transmitter on a frequency that Ponsonby stated lay between 700 and 800 Mc/sec. The signals received at Jodrell Bank were converted to a band 0-300 cps and recorded. Tapes were sent to the Soviet Union for analysis. Digital analysis of some of these tapes at the University of Manchester is in progress.

A major difficulty in the experiment was the inability to locate the frequency of the echoes, despite accurate Doppler predictions. Not until the signals became quite strong and a search could be carried out in real time, using an 11-channel spectrum analyzer, were echoes obtained (January 7, 1966). The echoes were at a frequency 124 cps higher than predicted on that day, but this offset declined during the following 3 months. It was not clear whether the information given concerning the frequency of the transmitter or the information concerning its precise location was in error. At all events, this difficulty precluded any accurate determinations of the Venus Doppler shift.

J. V. Evans (U.S.A.): Radar observations of Venus at a 3.8-cm wavelength, using the newly completed Haystack radar, were described. The low cross section (1 percent) reported earlier by Pettengill had caused a number of experiments to be performed to identify the scattering agency. Careful spectrum measurements

revealed that the Doppler width of the signals was always what one would expect, if the surface were the scattering agent. In addition, features in the spectra could be seen and identified with features reported by Carpenter at a 12.5-cm wavelength. The absolute Doppler shift was also found to be in agreement with that expected from simultaneous measurements at $\lambda = 23$ cm, made with the Millstone radar. Finally, precise ranging carried out almost simultaneously at $\lambda = 3.8$ cm and $\lambda = 23$ cm gave the same range for the peak echo to within ± 1 km, and, in addition, the echo shapes were found to be the same at both wavelengths. It was concluded, therefore, that the scattering arose from the surface and not in the atmosphere.

The rapid fall in cross section between $\lambda = 12.5$ cm ($\sigma = 11$ percent) and $\lambda = 3.8$ cm ($\sigma = 1$ percent) could not reasonably be attributed to a layer of lossy material overlying most parts of the surface, unless very artificial properties were assigned to it (for example, complete uniformity of depth and a very large loss target). Accordingly, a search had been conducted to seek effects of any atmospheric absorption that might be present. Atmospheric absorption should manifest itself in causing apparent limb-darkening, and a comparison of the 3.8-cm and 12.5-cm results showed that, indeed, Venus is limb-darkened at the shorter wavelength by an amount corresponding to 2 - 3 dB one-way atmospheric attenuation. Because the scattering law for the surface may not be the same at 12.5 and 3.8 cm, one cannot say whether there is a serious discrepancy between this result and the 5 dB one-way attenuation expected from the cross-section measurement. It may also be that the absorption is nonuniform across the disk—possibly less at the limbs than at the center (which contributes the bulk of the echo power). Fluctuations in cross section were observed over a period of months—the cross section occasionally rising to 3 percent. These increases seemed to be preceded by assymetry in the spectra, suggesting the passage of a "clearing" across the disk. Evans suggested that the absorbing agent might not be uniformly distributed throughout the atmosphere, and its abundance might be governed by major weather patterns. However, one could not rule out absorption in a dense (200 atm) CO_2 - N_2 atmosphere, as proposed by Barrett, if the height at the mean surface at the subradar point varied by several kilometers, since the absorption would then vary as the square of the atmospheric pressure.

V. R. Eshleman (U.S.A.): The Mariner radio-occultation experiment for Mars was described. Using only the S-band telemetry signals, the phase perturbations caused by Mars' ionosphere and atmosphere were determined on immersion, and the atmospheric effects were also recorded on emergence. These effects were apparent during the 15 sec prior to (and following) the occultation.

The entry point was at 50° S and 177° E, at 1300 local time, in the Martian winter hemisphere. The local solar zenith angle was $\chi = 67°$. An ionospheric layer of approximately Chapman shape was inferred, having a peak density of 10^5 electrons/cm^3 and a height of a maximum equal to 125 km.

For the atmosphere, one must assume some composition in order to convert the observed refraction to a density. Assuming 100 percent CO_2, the surface pressure was p = 4.9 mb, temperature T = 180° K, and lapse rate L = 0° K. The radius at this point was 3,384 km. The point of emergence was at 60° N and 36° W, at 2340 local time, in the summer hemisphere. The solar zenith angle was $\chi = 106°$ and no ionosphere was detected. For the atmosphere, again assuming 100 percent CO_2, p = 8.5 mb, T = 250°, and L = 2.5° K/km, up to 17 km, above which L = 0° K. The radius at this point was 3,380 km, and Eshleman suggested that the pressure differences stem from different local heights and imply that, on Mars, the mare ground is high land.

O. B. Slee (U.K.): The fine structure of Jupiter bursts appears to be caused by refraction by the interplanetary medium (solar wind), as suggested 2 years ago by Douglas. In new observations by Slee and Higgins, two interferometers were employed with baselines of 85 and 200 km, oriented NNE-SSW at f = 19.7 Mc/sec. By measuring the autocorrelation and cross-correlation functions of the received signals, the scale size and tangential velocity of the irregular diffracting pattern could be determined. These quantities could also be measured as a function of the elongation between earth and Jupiter at the sun. The velocity of the structure appeared to be ~900 km/sec, radial from the sun, and the structure size appeared to be of the order of 400 km. Dr. Slee stated that these values are overestimates, since earth and Jupiter lie in the diffracting medium, whereas the analysis assumes that all the diffraction occurs at a point equidistant between the two. This simplification should cause errors of the order of a factor of 2, so that the velocity should be more nearly 400 km/sec and scale 200 km.

J. N. Douglas (U.S.A.): Dr. Douglas described work carried out previously at Yale University with stations 120 km apart. By selecting from the records of Jupiter burst noise, sharply defined pulses (L pulses), it was possible to establish precise delay differences in the arrival of the signals at the two stations. About 200 days before opposition, the delay was about 0.5 sec and fell to zero at opposition. Some 200 days after opposition, it had risen again to about 0.5 sec, but now with the other station leading. This confirmed the model of a radial solar wind as the diffracting agency that gives rise to this structure.

J. H. Thomson: Dr. Thomson described cw radar observations of the moon carried on a day when the projection on the sky of the libration axis (i.e., the axis of apparent rotation to a terrestrial observer) wanders over 360°. From such observations, it is possible to construct a two-dimensional complex autocorrelation function (uv diagram). The Fourier transform of this function is the brightness distribution over the moon's disk. In preliminary measurements, a radar brightness map had been obtained at 410 MHz with an angular resolution of 3 min of arc (equivalent to about 300 km at the center of the lunar disk). After the mean variation of brightness over the disk had been removed, it was evident that the upland areas are $\sim$2 dB better reflectors than the mare. The map shown had side-lobe problems which were serious around the limbs, so that only for the central region had useful information been obtained. In future work, to be carried out with a larger dynamic range in the measurements and improvements in the computer programs, it is hoped to map the moon to a resolution of 1 min of arc by this technique.

G. H. Pettengill: Dr. Pettengill showed some delay-Doppler maps of the moon obtained at Arecibo by T. Thompson at 430 MHz. In these, a resolution of 40 km had been achieved, and this was sufficient to resolve all the larger craters. It was found that the newer craters (Tycho and Copernicus, for example) were all anomalously bright, with respect to their surroundings, by a factor of 5 to 10. The back wall of the crater was usually the strongest reflector, but the front wall facing the radar usually also provided a highlight. This work is continuing at Arecibo and Millstone, and maps are now being produced with a resolution of 3 km. Dr. Pettengill added that, since the range-Doppler technique is not useful near the center of the disk (because, there, a short pulse illuminates a

considerable area), the synthesis technique described by Dr. Thomson in the previous paper will also be employed, and the two methods should complement one another well.

Discussion

Dr. Moore entered a plea that the radar astronomers compute not only the fractional cross section of the entire planetary disk, but also the cross section of unit surface area at normal incidence. This requires a knowledge of the scattering law, but, in many cases, this is available. Dr. Moore also pointed out that the scattering law obtained in such measurements is based upon the assumption that the surface is homogeneous in character. If, however, the type of terrain were to vary systematically in some fashion with distance from the radar, the law obtained would be in error. Indeed, it would no longer be possible to describe the scattering properties of the surface by a single law. This is already the case for the earth, and obvious local anomalies on the surfaces of the moon and Venus have already been encountered.

Business Meeting

CHAIRMAN: J. P. VOGE

Chairman Voge introduced the newly appointed Chairman and Vice-Chairman, Saxton and Gordon, respectively, and announced the continuation of Herbstreit and Misme as the two secretaries.

Name Change

The title of Commission II has now officially been changed to "Radio and Non-Ionized Media." Chisholm voiced some objections to this name, saying that the title is too restrictive. Both Saxton and Waterman said that the commission is not restricted by its name, and that no name could be all-inclusive in designating the total interests of the commission. Voge concluded that any further suggestions for changes may be taken up with Saxton at the next General Assembly.

Resolutions

The Resolutions Committee, under Dr. Waterman, submitted a report, which is appended. There was discussion to the effect that item 6 of that report should have added to it the words "and on the transmissible spectrum." The exact wording of that change is to be left to the Committee. With that modification, the resolutions were adopted.

URSI-CCIR

Saxton, who is the Commission II representative on the URSI-CCIR Liaison Committee, had a report of that Committee to the effect that working groups shall be designated by the various commissions to handle problems set up by CCIR. The working groups should have the answers to the CCIR questions by the time the next meeting of CCIR takes place. URSI should designate in advance those who have the responsibility for the answers to the questions raised by CCIR. The Secretary General of URSI has already been requested by CCIR to provide the list of names of the chairmen of the various commissions who will be responsible for the specific answers. Norton indicated that it would be well not to have the CCIR people in URSI be given these working group assignments, but, rather, to have the work done by non-CCIR people. His fear was that nothing would come of such assignments. He felt the studies should be done independently of any carried on by CCIR. Burrows and Voge pointed out that it was the intent of the present resolutions to get the work done in time and with clear-cut responsibility. Herbstreit pointed out that it will be up to the chairmen to select the most qualified individuals in their commissions.

Herbstreit indicated that there were two questions already submitted to URSI. These are: (1) selection of a basic reference atmosphere; and (2) definition of terms used in tropospheric propagation. These two questions could be taken up in Commission II as a trial. Chisholm felt there should be some mechanism for keeping members informed on the questions. Voge suggested that the Commission II Chairman could submit these for inclusion in the proceedings.

Publications

131 In reply to a question by Voge, Herbstreit said the secretaries would have the reports on the present meetings just after the end of the meetings. He has many contributions for the discussions but, in some cases where the discussion is in response to a previously made point which has not as yet been handed in, the report would not make sense.

On the monograph, all papers are already in, except for the three by Möller, Pettengill, and Mayer. It is understood that these will be completed and sent to Atlas for reproduction and dissemination. They will also be sent to the scientific editor, who will include

them, ultimately, in the final monograph. The scientific editor for URSI must have the final copy in his hands by October 15 for reproduction by a photographic process; if not available by then, the paper will be replaced by its summary. Any changes to be made in the manuscripts can be made in the form of an addendum.

Voge clarified the difference between the proceedings and monographs. Both have information regarding discussions but, in the proceedings, the information is only on who took part in the discussions and, perhaps, the subject; whereas in the monograph, an attempt is made to bring out the essential points of the discussion.

Subjects for the next Plenary Assembly

The subjects proposed by Commission II members for revision by the new Chairman are:

1. Models of the troposphere (layers of all kinds). Unification of all experimental evidence from electromagnetic wave investigations in the formulation of a model of the troposphere.
2. Theoretical and experimental investigations of scattering and diffraction by irregular surfaces (including effects of vegetation and buildings) in propagation.
3. Optical propagation (including millimeter and submillimeter propagation).
4. Radiometry (including scientific aspects of the equipment required).
5. Discussion of reports of the Inter-Union Commission on Radio Meteorology.
6. Comparison of spectra obtained by different methods over the range of meteorological parameters.
7. Planetary atmospheres and surfaces (including subsurface propagation).
8. Electromagnetic techniques for measuring wind and turbulence.
9. Precipitation (including distinguishing precipitation from ground clutter).
10. Spatial distributions of atmospheric attenuation.
11. Noise.
12. Effects of noise on radio astronomy.
13. Meteorological satellites.

These will be modified and submitted to the national chairmen for additions, within the next year or so.

Symposia

The following three symposia were suggested:

1. A cosponsored symposium to be held at ITSA, ESSA, Boulder, Colorado, in 1967, on optical propagation.
2. A symposium on planetary atmospheres and surfaces, within the next 1 to 5 years.
3. A joint symposium with the Commission on Atmospheric Physics, on subjects included under items 1, 6, and 8 for the next General Assembly.

New Business

Smyth raised the point that researchers are aware of Tukey's work on the problems involved in chopping off a time sequence and thereby obtaining errors in spectra. He feels that this same error is implicit in our chopping off space measurement with discrete radar beams, but we are not taking this into account. Norton felt Smyth should write a paper suggesting the method for treating the problem correctly. Smyth accepted the challenge.

Adjournment

Saxton delivered a short speech thanking Chairman Voge for his excellence in presiding over Commission II for the past six years.

Report of the Resolutions Committee of Commission II

The Resolutions Committee met on September 8 and examined the Commission II resolutions that had been adopted at the 14th General Assembly in Tokyo in 1963. It noted that Resolution II.1 adopted in Tokyo, with respect to the terms of reference of Commission II, has now been approved by the Executive Committee and endorsed by the General Assembly, and its provisions have been carried out. Therefore, no further statement with respect to the terms of reference is needed.

With respect to the other resolutions adopted in Tokyo, the present Resolutions Committee, being composed of largely the same membership as its predecessor, was impressed by the high quality of these resolutions and considered that they should be continued, with only a few revisions. Of the resolutions listed below, only the first is new. The others are either the same or slightly revised versions of the resolutions adopted in Tokyo.

We recommend:

1. That the Inter-Union (URSI-UGGI) Committee on Radio Meteorology be continued, with particular emphasis on the organization of meetings of small working groups involving special topics.

2. That, in space studies, further attention be given to measuring characteristics of planetary atmospheres and surfaces, including those of the earth, as viewed from space; controlled laboratory and model experiments may be of assistance in this endeavor.

3. That there be more applications of the theory of radiometry and that more radiometric data be taken on terrestrial and atmospheric radiative energy as regards: (a) the effect on atmospheric structure and (b) the effect on sensitive receiving systems.

4. That attention be given to coherent millimeter, submillimeter, and optical waves as regards: (a) their propagation through the atmosphere and (b) their use in providing additional information on atmospheric structure, including both variations in refractive index and in the intensity and drop-size distribution of precipitation.

5. That continued attention be given to gathering further data on surface and subsurface propagation as regards: (a) determining characteristics of the medium and (b) measuring the effects on signal level, angle of arrival, etc.

6. That experimental and theoretical methods of studying the structure of refractive index irregularities be exploited; specifically: fluid-mechanical theory, higher resolution systems, simultaneous vertical and oblique radio measurements (including Doppler techniques), simultaneous radio and meteorological measurements (including interdisciplinary cooperation); and, also, that stress be placed on finding the upper limit of accuracy imposed by the atmosphere on measurements of range, angle, and Doppler effects.

7. That continued effort be devoted to improved theories and models of the atmosphere providing adequate explanation of propagation phenomena—in particular, the question of effective antenna gain as a function of distance, frequency, etc.

COMMISSION II / SESSION OF SEPTEMBER 13 (A.M.)

Propagation Below the Earth's Surface

CHAIRMAN: J. P. VOGE

REVIEW OF RADIO PROPAGATION BELOW THE EARTH'S SURFACE

J. T. de Bettencourt

Dr. de Bettencourt outlined the various mechanisms of propagation through the earth: (1) the "up-over-down" mechanism, which is most efficient for horizontal, electric dipoles coaxially arranged just below the earth's surface; (2) propagation between vertical electric dipoles immersed in a lower conductivity rock below an overburden; and (3) waveguide modes in a very deep thick rock layer of very low conductivity (about 10^{-6} mho/m) sandwiched between a more highly conducting overburden on top and a highly conducting region below at the Mohorovičič (Moho) discontinuity. A slide illustrated, in a simplified manner, the geological structure of the earth's crust. Near the earth's surface, to a depth of perhaps a few kilometers, there is an overburden, or layer of weathered material or sediments, followed in depth with fractured granites. The granite becomes more compact with depth and has lower conductivity, which is underlain with a lower conductivity basaltic layer. At the bottom of this is the higher conductivity Moho region, the depth of which differs under mountains from the depth under the ocean. The conductivity increases with depth in this region because of the high temperature.

Propagation in lossy media was limited to discussion of waves in rock media, since sea-water propagation was to be discussed separately later. The loss tangent controls propagation constants

markedly, and was illustrated by equations and slides. The predominant effect of loss tangent is that, at low frequencies, where it is large, the attenuation constant is high and the wavelength in the medium is small, compared with that in air; the attenuation and phase constants vary with the square root of frequency, giving a strange filter characteristic to the earth-propagation medium.

Data were presented for variation of conductivity with depth from drill holes into the crust. Based on these, plus data from laboratory measurements of rock samples (cores), plus those from surface sounding techniques, an estimate of depth profiles can be made. One example due to Levin (U.S.A.) was shown, illustrating an estimate of depth dependency of conductivity and dielectric constant at 1 kHz, from which the attenuation constant was calculated and plotted; this showed low values (a few tenths of a decibel per kilometer) at great depths. The conductivity variation with depth was also determined from input impedance of electric dipole probes; the conductivity over a horizontal range was determined from the measured mutual impedance between broadside vertical electric dipoles inserted in separated drill holes.

One advantage of propagation entirely within the earth's crust at modest or great depths is the low noise level. This is because the rock and sedimentary overburden regions above attenuate the atmospheric noise to levels limited by the receiver input circuit, depending upon frequency and receiver depth. This is even more true for the deep waveguide mechanism, which should have low attenuation because of the low rock conductivity for that region.

In summary, Dr. de Bettencourt emphasized the need for more data on subsurface noise levels and added that further theoretical work on waveguide mechanisms awaits the availability of deeper holes. A great deal of work has been performed in this new field, but much of its dissemination has been limited to unpublished reports. Besides this first URSI report, there does exist a comprehensive publication in the May 1963 issue of the IEEE Transactions of GAP. Other work outside the United States has been performed, but is not reported in national committee reports available. It was pointed out that an "early worm" system of efficient communication by the waveguide mechanism depends upon the availability of much deeper (greater than 3 km) holes which are very costly, so that the region of lowest conductivity could be reached in the crust.

Prof. Bouix (France) observed that modes in a dissipative waveguide are different from modes in a nonabsorbing medium. G. Francescetti (Italy) said that some preliminary qualitative experi-

ments have indicated the utility of increasing the effect of a magnetic dipole by ferrite cores, and the generation of an electric dipole antenna by the use of toroidal coils with ferrite cores. De Bettencourt agreed that loop and dipole studies in mines were useful and pointed out that Bitterlich's work (Austria) in mines is closely related. In reply to a question by I. Gerks (U.S.A.), Dr. de Bettencourt said that most experimental holes were filled with water, and that the diameter makes little difference. Dry holes with antennas (linear) act like coaxial lines with air dielectric, logarithmically sensitive to the diameter.

Dr. R. K. Moore talked on fundamentals of antennas in conducting media. The material was drawn largely from his doctoral thesis at Cornell University in 1951 and a paper published in the IEEE *Transactions*, *APII*, May 1963. Moore surveyed tutorially the following topics: the vital difference between antenna performance in free space compared with that in dissipative media, due principally to high exponential attenuation; the effect of location of the exciting source on the pattern; insulated antennas with open- or short-circuited termination as effective underwater radiators; and the physical interpretation of the radiation resistance of a linear dipole. Swain's analysis of an idea of Anderson and Moore concerning the use of ferrite toroids to form an equivalent electric dipole was explained.

Prof. Bouix presented an informal review of the recent NATO symposium on communications beneath the surface (April 23-29, 1966, at Paris), both subterranean and submarine. He emphasized the aspects of underwater propagation at extremely low frequencies, including the work of Gutton and Gabillard.

Chairman Vogе, in closing the last session of Commission II, commented on the expansion, during 1960 to 1966, of the scope of the commission's interest from about 15 km of troposphere to the inclusion of the earth's atmosphere to about 100 km and the earth's crust to a 25-km depth, as well as the moon, Mercury, Venus, Mars, and Jupiter.

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COMMISSION III

IONOSPHERE

CHAIRMAN: J. A. RATCLIFFE (U.K.)

First Business Meeting

CHAIRMAN: J. A. RATCLIFFE

The Chairman indicated the following agenda for this meeting:

1. Discussion of methods of appointing the Commission III Chairman and Vice-Chairman
2. Arrangements for technical sessions
3. Publications of Commission III
4. Preparation of a report on the solar-terrestrial physics symposium in Belgrade
5. Consideration of working parties
6. Consideration of officers for Commission III
7. Other business

The Chairman indicated that the Board of Officers had requested comments from each of the commissions relative to continuing the various chairmen in office for more than 3 years. In the past, commission officers have generally served for two 3-year terms. The proposed system would be to elect a chairman and vice-chairman for a single 3-year term. At the end of this term, a new vice-chairman would be elected for the next term, and the vice-chairman completing the term would normally be elected as the next chairman. This system would provide continuity and an opportunity for more people to have the responsibility of being commission chairmen. The commission members indicated general agreement with the proposed change.

The Chairman indicated that the review papers would be followed by discussions of points germane to the session. Each person desiring to discuss material was to make his request known and present a 200-word abstract to the Commission Chairman. It was

announced that Dr. A. M. Peterson (U.S.A.), reviewing a paper on "Effects of Nuclear Propagation Phenomena" for Commissions IV and IVa, would present this paper to Commission III on September 14. Delegates wanting to present new topics were to contact Dr. Little (U.S.A.) so that he could organize his session.

The Chairman announced that Dr. G. M. Brown (U.K.), the present scientific editor for Commission III, had agreed to accept the position for another term. The material for inclusion in the report was to be the invited review papers and significant comments which were made during the discussion, providing the commissions were furnished an abstract for each by the authors. The speaker giving the main review paper was to summarize and report on the discussion.

The Chairman indicated that several questions had been forwarded to Commission III that required consideration, and he appointed the following individuals as chairmen of working parties to consider the topics listed:

1. Mr. W. Piggott (U.K.)	Topside sounding nomenclature and ducting (a CCIR question)
2. Dr. A. H. Shapley (U.S.A.)	Key ionosondes (iF_2) numerical mapping problems (CCIR), and sporadic-E predictions
3. Dr. R. Wright (Jamaica)	Reduction of drift data
4. Dr. K. Rawer (Germany)	Reduction of absorption data
5. Dr. O. Villard (U.S.A.)	Transequatorial propagation (CCIR)

The working parties are to recommend appropriate action, which can include: (1) that no action be taken; (2) that a resolution be prepared for consideration by the commission; or (3) that it will be necessary to continue the working party and to have it report at the 16th General Assembly. Prof. Villard suggested that any consideration of propagation predictions should consider the impact of oblique ionosphere sounders. The Chairman assigned this item to Dr. Shapley's working party. Dr. Bibl (U.S.A.) made a suggestion, which was adopted, that the same group consider both vertical and oblique sounders. Dr. E. K. Smith (U.S.A.) recommended that the CCIR question concerning methods to be used in forecasting of sporadic E be assigned to Shapley's working party.

It was noted that a report on the Belgrade symposium on solar-terrestrial physics would be made at a joint technical session of all commissions on September 9, by Professors Booker (U.S.A.), Dungey (U.K.), and Bowhill (U.S.A.).

The Chairman noted that R. Knecht (U.S.A.) was the English-speaking secretary and that the present French-speaking secretary was Dr. Lepechinsky (France) [to be replaced by Dr. du Castel (France)]. The Chairman indicated that, after considerable individual discussion with official members of the commission, he was proposing the following slate of officers and was requesting of the commission that: (1) a single name be forwarded to the Official Board for consideration as the new chairman and that it be the present Vice-Chairman, Dr. C. O. Hines; and (2) that four names be furnished to the Board of Officers for their selection of a vice-chairman; and that they be: Dr. F. du Castel (France); Dr. B. Landmark (Norway); Dr. A. P. Mitra, Dr. K. Rawer (Germany). The proposed slate was approved by the Commission.

Prof. Bowhill (U.S.A.) announced that COSPAR, in a recent Vienna meeting, had proposed to adopt an International Standard Ionosphere similar to the Standard Atmosphere. He proposed that, if URSI wanted to furnish an input, action would have to be taken at this General Assembly. Dr. Schmerling (U.S.A.) noted that Prof. S. Silver was the official URSI representative to COSPAR. The Chairman assigned this question to Mr. Shapley's working party for preparation of a resolution.

Dr. Ranzi (Italy) suggested that the Chairman provide copies of the review papers to each of the official members prior to making them available for general distribution. The suggestion was adopted.

The Chairman announced that a second business meeting of Commission III would be held on September 13.

D-Region Structure and Formation

CHAIRMAN: J. A. RATCLIFFE

REVIEW PAPER

B. Landmark (Norway)

It was stated that Faraday rotation techniques probably provide the best experimental procedure in rocket-borne determinations of electron density (N) and collision frequency (ν), utilizing radio waves as the exploring tool. Rocket-probe techniques were said to be complicated in their interpretation, although parachute releases simplified these problems considerably. It was also stated that ground-based radio experiments, including lf, vlf and hf, and absorption, are good techniques, as are wave-interaction and partial-reflection experiments.

N(h) Profiles

Slides were shown giving N(h) profiles over D-region heights, as obtained by all the above techniques, for different latitudes, diurnal and seasonal times, and solar cycle periods. In summary:

1. It was found that N at noon, for altitudes from 65 to 95 km, was essentially the same over the latitudes 20° to 70° N, under quiet conditions.
2. Results showed N(h) diurnal variation of a factor of 10, at low latitudes.
3. Diurnal variation, at high latitudes, of N(h) was very small.
4. Day-to-day variations in N(h), at mid-latitudes, were large in winter but small at other times of the year.

Brief Consideration of Disturbed D Region

Slides were shown on N(h) profiles for the following:

1. During a sudden ionospheric disturbance (SID)—considerable increase in N at lower levels, with little change at higher levels.
2. Auroral event—great increase at mid-altitudes (80 to 90 km).
3. Polar cap absorption (PCA)—large increase at essentially all D-region altitudes.

Region Formation

Ionizing mechanisms were discussed, and it was stated that this factor appeared to be fairly well understood. Reaction rates were considered, and the presentation indicated that this was in a somewhat confused state at present. Implied movements at D-region levels were essentially unknown, and Landmark did not consider them further.

The Nicolet-Aikin theory of D-region formation was outlined, and it was stated that this is the basis for present work in this area. The heights for unit optical depth of the solar spectrum were outlined. Landmark described: hard x-ray enhancement during solar flares; effects of cosmic-ray radiations as a function of latitude; Lyman-α and NO electron production over the relevant height range; and soft x-ray production near the top of the D-region. He mentioned possible effects of metallic meteor debris as well as sodium, etc.

He briefly outlined the mass-spectrometer observations of Narcisi, and illustrated the great importance of such work. He pointed out the importance of obtaining neutral NO-height distributions as well as heavy-particle constituents. He believes that the relative lack of diurnal variation in N at high latitudes is due to a continuous influx of particles—possibly electrons.

Reaction Rates

Landmark briefly outlined the continuity equations at D-region levels and indicated that electrons, negative ions, and positive ions must be considered. He stated that O_2^+ and NO^+ are probably the most important, while N_2^+ is of lesser importance because of its rapid loss rate. As for the importance of negative ions, he assumed that O_2^- is the most important, and gave relations and reaction rates for three-body attachment, photodetachment, and

collisional detachment. Detailed measurements on positive and negative ions remains one of the most important problems in research at D-region height levels.

Landmark outlined the effects of ions in polar regions where photodetachment during the long periods of illumination and collisional detachment during darkness should predominate. He summarized Reid's results on optical versus ultra-violet (uv) processes, which are apparently effective at these latitudes.

He also presented slides and discussed in some detail Narcisi's D-layer mass-spectrometer results for positive ions.

Major Problems

In Landmark's opinion, the following are several of the major problems requiring experimental and theoretical studies:

1. Although such variations as electron-density diurnal, seasonal, height and time are reasonably well known, this is not true for special periods such as sunrise, sunset, and eclipse.
2. A major problem at the moment is the determination of positive- and negative-ion densities as functions of height, time, latitude, and the constituents involved.
3. In particular, further progress in D-region studies requires negative-ion measurements and a determination of the processes involved.
4. He indicated that ionizing-radiation measurements are needed at D-region levels, in connection with simultaneous satellite observations.
5. While movements were not considered in his survey, Landmark stressed their importance, as well as that of the developing field of troposphere-mesosphere relationships.

Discussion, Paper Reports, and Comments

The following were presented as discussions and related contributions by the speakers indicated.

Belrose (Canada): Dynamics of D-Region Structure. He stated that random samples of N(h) profiles are inadequate, and stressed the need for diurnal and other variation studies. With this in mind, he discussed the D-region N(h) through: (1) sunrise; (2) winter variability; and (3) latitude variation. He also:

1. Presented slides of N(h) obtained by Smith at Armidale from wave interaction, which stressed buildup at low altitudes during sunrise.

2. Presented slides of N(h) obtained by partial-reflection techniques at high latitudes over seasonal intervals. He pointed out winter variability at altitudes of less than 80 km which indicated no correlation with 30 mb temperature, but correlated with the K index.

3. Reported on N(h) for wide-latitude variation in Canada. At low altitudes (50 to 70 km) he finds latitude variation which is the inverse of that to be expected for a cosmic-ray ionizing source. He concluded that, at low levels, the latitude variation was wrong for a cosmic-ray ionization source (winter variability in N(h) for heights less than 80 km).

Bowhill (U.S.A.): Rocket D-Region Measurements and Their Interpretation. He discussed rocket N(h) profiles—seasonal, latitude, and diurnal variation through sunrise—obtained from differential absorption and Faraday rotation. He pointed out the following:

1. For a given mid-latitude location, for a constant polar-zenith angle of 60° in April, June, and December, the N(h) profiles essentially overlap in the E region, but there are wide variations from 60 to 90 km.

2. For latitude variations from 16° N to 48° N magnetic, E profiles are found to be the same. At low altitudes, latitude variation in N(h) is contrary to that to be expected if cosmic-ray ionizing effects predominate.

3. At a given mid-latitude location, N is found to be less than $1/cm^3$ for altitudes less than 80 km and $\chi = 105°$. The same is true for $\chi = 94°$, with a maximum appearing at 70 km for $\chi = 83°$.

147 Bauer (U.S.A.): Temporal Variations in N(h) Rocket Measurements. He quoted Kane's Faraday-rotation results obtained in New Zealand. For χ varying from 95° to 84° to 74°, N varied from 10 to 100 cm^3. Below 80 km, he noted great change as χ decreased.

Willmore (U.K.): Satellite Solar Hard X-ray Spectra. He discussed the 1° to 8 Å solar-spectrum measurements being obtained with the orbiting astronomical observatory (OAO) satellite. He pointed out that the sensitivity curve of the spectrophotometer utilized tends to bias the 6Å to 8Å region, whereas major changes in the actual solar spectrum probably occur in the 1 to 3 Å region.

Lauter (East Germany): He indicated that vlf reflection height varies by about 1 km over long intervals of time, and this must be considered in solar spectrum measurements.

Ratcliffe: Long-Wave Determination of N(h) Profiles. He presented slides of N(h) profiles deduced by Deeks from a long series of various ground-based long-wave measurements. He considered diurnal and seasonal profile variations, as well as profiles during eclipses and for solar cycle variations.

Reid (U.S.A.): He described, in some detail, Ferguson's laboratory determinations at ESSA Boulder, of negative-ion reactions, which may be dominant in negative-ion production and loss at D-region heights. In addition to the new rate determinations, the scheme involves the transfer of charge to and from O and O_2 with the formation through O_3^- and CO_2 and NO of stable NO_3^-.

In terms of the scheme proposed, NO_2^-, NO_3^-, and CO_3^- may be the dominant ions while O^-, O_2^-, and O_3^- are minor ions. He said that the scheme may satisfy many of the experimental observations, including his own work on optical versus uv ionic detachment, and it may be a very important development in D-region studies.

Pfister (U.S.A.): Computer Solutions of Continuity Equations. He showed results of applying Keneshea's computer program to yield temporal variations of the variables in the complete continuity equations. The program handles 15 quantities and obtains time-independent reaction rates for the various processes, based on observational data on certain of the quantities (available as an AFCRL report). He also showed application to a Churchill eclipse series of rocket firings. Slides of N(h) and charged- and neutral-particle height distributions, as a function of time, were shown. He found a 2 order of magnitude change in N in the height range of 60 to 70 km during the eclipse, but little change at greater heights.

Ramanathan (India): On hf oblique recordings, he found periods when daytime signal strength (and, therefore, N) had a larger than usual increase which lasted for several days.

Bailey (U.S.A.): Churchill rocket observations into an aurora showed a persisting nighttime rapid increase in loss rate from 80 km downward.

Bowhill: He stated radio measurements yielding N are reaching their limit of usefulness and there is a need for ion measurements. He suggested looking for photodetachment measurements as a means of distinguishing between the constituents involved, in terms of the different electron affinities associated with different negative ions.

Reid: He pointed out that most heavy constituents do not have abrupt affinity-energy distributions, and the above scheme would probably not work.

Willmore: He reported on D-region, rocket ion-density measurements associated with obscuration of x-ray sources on the sun. He found an abrupt change in ion content as the x-ray source appeared—between about 65 and 80 km. He concluded that electrons in the above height range were all associated with 1 to 2 Å radiation.

Friedman (U.S.A.): Satellite Observation of Solar-Cycle Variation in X-radiation. He reported on solar-cycle variation of solar x-radiation intensity variations near 50 Å associated with E-region production and harder x-radiation, associated with the D region, as follows:

1. Near 50 Å rather abrupt increases in solar radiation at the sunspot maximum are observed, with relatively constant intensity over the balance of the cycle. From 0 to 15 Å, the variation is sinusoidal.
2. During a nonactive solar period, the 0 to 8 Å intensity is approximately constant; a buildup occurs in the 0 to 3 Å range during an active period.
3. Angular distribution of 0 to 8 Å radiation is a function of the size of the x-ray source on the sun. For "normal" sources, this is about 1 min of arc. For larger sources, the angular distribution increases somewhat. The largest source appears related to the angle subtended by a plage area.
4. He finds that the active region can produce a factor of 50 variation in the intensity near 15 Å.
5. He stressed the need for determination of Schumann-Runge penetration, in terms of H production, and its interaction with O_3, possibly down to as low as 20 km above the earth's surface.

Willmore: Duration of High-Radiation Levels. He observed that high radiation levels, 10^{-5} to 10^{-4} erg/cm^2 sec^{-1} in 0 to 3 Å, may last for a complete solar rotation.

Maeda (Japan): High-Latitude X-ray Observations. He indicated that rocket x-ray observations at high latitudes appear to indicate a source associated with particle precipitation.

Belrose: Nighttime Latitude Effects. He discussed nighttime sources of ion production as a function of latitude for altitudes below 100 km.

1. At middle latitudes, N variations were found at night which must involve some as yet unspecified source.
2. At auroral latitudes, variations may be attributed to scattering of the ionizing source into a nonilluminated region. There is little change from day to night.
3. At high latitudes, a continuous source is required. Below 80 km, a great change in day-to-night values is observed.

D-Region Collision Frequencies, Relation to Stratosphere

CHAIRMAN: K. RAWER (GERMANY)

REVIEW PAPER

W. Piggott (U.K.)

Mr. Piggott's review of collision frequency in the D region began by referring to the fact that a number of meetings and symposia have recently been devoted to this topic; hence, he did not propose to review the whole subject but simply to highlight certain aspects of the collision-frequency problem. Calculations of hf radio absorption are, of course, dependent on the collision-frequency model adopted. Piggott stressed the importance of including information on the collision frequency assumed in D-region electron-density-profile determinations. Single experiments typically give only the ratio of N/ν (or the product of $N \times \nu$) and do not allow the two parameters to be individually determined.

A review of some of the basic theory underlying the concept of electron-collision frequency was given. Piggott then reviewed the state of the pertinent laboratory experiments. It appears that the situation with respect to an N_2 atmosphere is well in hand. The collision cross section for nitrogen has been measured, and increases approximately linearly with velocity. The situation with respect to O_2 is far less favorable because of the difficulty of doing the laboratory experiment at the proper temperature. In any event, the mean collision frequency of the atmosphere at D-region levels is largely (85 percent) controlled by N_2; hence, the O_2 uncertainty is not too serious, and ν is effectively proportional to the atmospheric pressure.

Piggott next presented the results of some theoretical computations of mean collision frequency using a standard reference atmosphere (like CIRA 1965) and the laboratory measurements referred to above. At 80 km, $\nu_{(mean)} = 6.5 \times 10^5$/sec, compared with 7.5×10^5/sec for the same altitude from laboratory data.

Considering now the observational data on ν, Piggott reported better internal agreement is possible when the data are divided into two groups: (1) winter and spring; and (2) summer and fall. The winter data were then shown to be consistent, in height variation, with values to be expected theoretically, using the Standard Atmosphere approach. The summer data were also consistent with theoretically deduced values, but a slightly different atmospheric model had to be used to get a fit. The difference between the two sets of points amounted to about 3.5 standard deviations, or about 70 percent, with summer value higher than winter value.

Examination of the atmospheric-pressure differences that are observed between summer and winter and deduction of theoretical mean collision frequencies for the two seasons produces results in good agreement with the seasonal differences detected by using radio methods. Piggott drew the conclusion that collision frequency in the 60- to 90-km height range is, therefore, predominantly controlled by the pressure of the nitrogen that is present. It was then pointed out that straightforward pressure change alone could not produce the observed ionospheric changes; for example, the propagation of long waves (they would result in a change in geometric height only). Temperature changes that, in turn, affect the ionization equilibrium are probably involved in some as yet unexplained way. To produce the observed effects on ionospheric absorption at hf, increases in electron density of 1 to 2 orders of magnitude over a considerable height range are required.

Piggott also showed that, due to pressure variations with latitude, latitudinal variations of mean collision frequency at a constant height could be expected.

He then turned to a review of the situation above 80 km, showing a comparison of the theoretically deduced pressure-dependent values of collision frequency with the observed values (in the height range of 80 to 140 km). Between 80 km and about 100 km, the theoretical and observed values were in generally good agreement; above 100 km, the observed values were systematically greater than the theoretical curves. Piggott claimed that this could come about in either of two ways (assuming, of

course, that the observed values are reliable): (1) if electron temperature is much higher than gas temperature; or (2) if a minor constituent with an enormous collision cross section is present.

Discussion

Suchy (Germany) discussed the importance of the angular and speed "weighting" functions in determining collision frequency and he pointed out the need to take care in distinguishing between "mean collision frequency" and "most probable collision frequency."

Bowhill reported on the results of several rocket flights in which both differential-absorption and Faraday-rotation experiments were flown, allowing determination of collision frequency in the overlap region (80 to 95 km). Also flown were sensors operating in the 1216 Å and 1450 Å range. Hence, he was able to obtain both collision frequency and, by measuring the extinction of the uv light, the neutral density. He showed a table comparing electron temperature, deduced from collision frequency with the use of the Phelps and Pack relationship, with neutral temperatures for five flights. From the fact that the values seem to parallel one another very well, Bowhill determined that one of two conclusions was possible: (1) if we believe the Phelps and Pack result, thermal equilibrium between the electron and the neutral gas does, in fact, exist; or (2) if we grant that thermal equilibrium does exist, the results verify the Phelps and Pack relationship. He seemed to feel that, as a consequence, in future flights one need only measure uv extinction in order to determine collision frequency.

Belrose reported on determinations of ν with the use of ground-based partial-reflections technique. The best information on collision frequency is obtained at 60 km. Regarding seasonal changes in collisional frequency, he reported a negligible change at low latitudes (White Sands) and changes of a factor of 1.5 to 2 at high latitudes (60°), but no apparent changes in his data collected at Ottawa (45°). A review of the average departure in the height of neutral-density surfaces over Ottawa (meteorological data) revealed that Ottawa is anomalously located with respect to a large pressure system during the winter months, and Belrose felt that this could mask any seasonal variation.

Bibl discussed the effects of various degrees of patchiness in the E-region structure on hf-absorption measurements, suggesting that apparent anomalies in absorption data could result from changing reflection mechanisms in the E layer.

In his discussion of relationships between the D region and the stratosphere, Piggott first reviewed the essential features of the winter anomaly in hf absorption, including the following: the D region must be solar illuminated; there is a barrier at the auroral zones; days of high absorption bear no relation to high magnetic or solar activity, etc. He then reviewed the evidence for an association with lower atmospheric phenomena, presenting diagrams showing similar seasonal variations (with cos χ) of neutral density (at 70 km) and vertical-incidence absorption. Both show "figure 8" types of annual variations with pronounced winter anomalies. Piggott observed that winter anomalies in absorption tended to be correlated over areas of approximately 1,000,000 km^2. He next reviewed the ionospheric consequences of a particularly strong stratospheric warming in January 1963, first noting that no ionospheric effects were seen over North America, though the warming was most intense there. He conjectured that perhaps the relatively high magnetic dips of most of eastern North America were involved in some way. Results showing the correlation between 10 mb temperatures over Berlin and ionospheric absorption at Landau during this event were presented, together with the results of some statistical studies of Shapley and Beynon on a number of smaller events. The results suggest simultaneous effects in the D region and in the lower atmosphere; that is, no systematic time delay of one effect relative to the other can be detected in the observations.

Piggott summarized his remarks by saying that he felt that the situation with respect to an explanation of the observational phenomena remains confused. He seemed to feel that the most likely explanation would involve a modification in the distribution of minor constituents due to temperature-related effects in the atmosphere. He also felt that diffusion and/or transport of minor constituents might play an important role.

Rawer showed a curve of monthly averages of absorption at Freiburg for a 6-year period, from which solar-cycle and seasonal trends had been removed, yet with a ± 40-percent variability from one month to the next that remained to be accounted for.

Shapley (U.S.A.) discussed the question of a time lag between the stratospheric and ionospheric effects. Apparently, based on observations obtained primarily below 30 km (and a few isolated rocket observations at greater heights), meteorologists would like to see such a time lag extending upward into the ionosphere. He gave arguments supporting the view that his data, which show no time lag, are as

valid (or perhaps even more valid) than the pertinent meteorological data.

Bowhill presented two electron-density profiles obtained from rocket flights of December 1965 and January 1966. The first flight occurred on December 15, a day with rather low wintertime absorption, as measured by the standard hf ground-based techniques. The second flight was purposely delayed until a day of high absorption (January 10). It was found that the electron density on the January 10 flight, at 82 to 83 km and higher, was a full order of magnitude greater than that of the December flight. He called attention to the fact that the 82- to 83-km lower boundary of the large increase in electron density also represented the usual lower boundary of the nighttime D region. He concluded by saying that he felt that mesospheric heating, possibly associated with the downward flow of atomic oxygen, might be responsible for both the ionospheric effects and the stratospheric warning.

Beynon (U.K.) reported that E-region equivalent heights also showed a 5- to 6-km increase, centered on times of stratospheric warming, and supported Bowhill's suggestion that both the ionospheric and the stratospheric effects could have their origin in the mesosphere.

Hines (U.S.A.) introduced the concept of planetary waves into the discussion and pointed out some of the properties of these waves. Wave number, wind structure at middle heights, and other factors will play important roles in determining the phase relationships of effects occurring at different altitudes. He also made the suggestion that the existence of the extensive Rocky Mountain range in North America and its marked effect on wind structure at upper levels might account for lack of a correlation between stratospheric warmings and ionospheric phenomena on that continent.

155 Reid stressed the importance of considering not only temperature but wind-flow and circulation patterns, when looking at stratospheric-ionospheric coupling.

Belrose urged that ionospheric workers undertake more synoptic programs similar to those undertaken by the meteorologists. This would help in recognizing and studying movement patterns.

Lauter showed results concerning the frequency dependence of the winter anomaly in hf radio absorption. The effect is strongest around 1 MHz and disappears entirely at 128 kHz. The minimum absorption on all frequencies occurs in the spring

period, for unknown reasons. He also showed results indicating a good time association between the breakdown of the 10-mb polar vortex and periods of high radio absorption. Finally, he presented some data suggesting that D- and E-region drifts are also related to lower-atmosphere phenomena.

The Ionospheric F Region and the Magnetosphere

CHAIRMAN: S. A. BOWHILL (U.S.A.)

The session was divided roughly in two. The first was devoted to the mean properties of the F region and magnetosphere, such as electron density, ion composition, and temperature. Since there had been an extensive discussion of ionospheric temperature at the Belgrade symposium, the Chairman requested that authors refrain from simply repeating work reported at Belgrade. The second half of the session was devoted to the subject of ionospheric irregularities.

In the opening review paper, W. E. Gordon summarized the information on ionospheric structure which has been obtained during the last three years from the incoherent backscatter technique. He first described the situation as it was at the last URSI General Assembly. Most of the quantitative information obtained by this technique on ionospheric structure has been produced since that time, and he added that, since the data represent a wealth of detail, only a few summarizing remarks were appropriate in this report. Reasonably regular observations are now being made at four latitudes near the 15th meridian (Prince Albert, Millstone, Arecibo, and Jicamarca), as well as at Nançay, in France. Electron-density profiles extend from below 200 km (50 at Arecibo) to above 1,000 km (10,000 at Jicamarca). The ion temperature during the day increases from about 1,000° K near the F-region peak, to several thousand degrees at about 800 km, and appears to remain constant above that height. At night, the ion temperature is about a factor of 2 smaller. The relation of the electron temperature to ion temperature is sensitive to latitude effects. Ratios of T_e/T_i range from 1 to nearly 5, depending on the time of day and

the geographic location. Information is also being obtained on the three major ion constituents of the high atmosphere. The dominant ion in the F region is O^+, changing to H^+ at about 1,000 km by day and at about 700 km by night. He^+ is observed occasionally in the transition region but has not been seen to exceed 10 to 20 percent of the total ion composition.

Incoherent backscatter has also been used for a number of important observations related to dynamic processes in the ionosphere. For example (see the reference to Carlson in the text following), photoelectrons in the 1 to 30 eV range have been seen to affect the ionosphere at the magnetic-conjugate point, particularly during the sunrise hours. Also, it has been possible to delineate a wave structure in traveling ionospheric disturbances over the height range from 150 to 800 km.

In the discussion following Gordon's review paper, J. V. Evans (U.S.A.) noted that it has been possible to extend the Millstone observations of ion composition to indicate the ratio of O^+ to the combined content of NO^+ and O_2^+ in the height range of 130 to 250 km. He noted that there may be a seasonal variation of this ratio. Evans also emphasized that at Millstone T_e/T_i does not fall to unity, even as high as 800 km, in contrast to the results obtained at the more southerly stations. He called attention to a paper given by P. Banks at Belgrade in which theoretical support for this behavior was demonstrated.

Gordon had called attention to the fact that the incoherent-scatter observed values now seem to agree very well with those obtained by other methods. However, he did draw attention to a discrepancy indicated in a comparison with the results obtained with the Ariel satellite during 1962.

Willmore commented on the probability of instrument difficulties during that period. However, he noted that since the incoherent-scatter observations used in the comparison were made during 1963, some real differences may be indicated.

J. H. Chapman (Canada) reported on a new technique developed by E.L. Hagg for measuring extremely low electron densities from the Alouette satellite (E. L. Hagg, "Electron Densities of 8 to 80 Electrons per cc Deduced from Alouette 2 High-Latitude Ionograms," to be published in the Canadian Journal of Physics). The method makes use of beats between observed oscillations associated with the electron-gyrofrequency and the upper-hybrid frequency. These extremely low electron densities often appear in the polar ionosphere above 60° geomagnetic latitude and at

heights from 1,500 to 3,000 km. The southern boundary of the low-density region appears to coincide (in L value) with Carpenter's "knee" and Muldrew's "trough" during magnetically quiet periods. The region of low electron density also appears to be filled with irregularities of electron density (a paper of G. L. Melius and G. E. K. Lockwood, to be published in Space Research, Vol. VII).

J. Belrose described the use of proton and helium whistlers as a means of measuring the major ion abundances in the ionosphere (details on the technique to be presented at a later session during this General Assembly). Since the Alouette 2 orbit is elliptical, data can be obtained on the ion composition as a function of height. Belrose gave the following table as representative of preliminary results obtained at middle latitudes:

Height/km	Content		
	H^+	He^+	O^+
1,027	0.65	0.16	0.19
1,104	0.71	0.15	0.14
1,457	0.87	0.04	0.09

From preliminary data on diurnal and latitude dependence of the ion composition, Belrose drew the tentative conclusion that conditions are likely to depart significantly from diffusive equilibrium.

H. Friedman then summarized the mass-spectrometer results obtained by Hoffman and Holmes of the NRL from the Explorer 32 satellite. In addition to the major constituent ions H^+, O^+, and N^+, they also found traces of D^+, He^+, O^{++}, and a number of others. The crossover from O^+ to H^+ as the major constituent seems to occur generally near 1,000 km, but the concentration of N^+ ranges from 5 to 30 percent seems to occur at the same altitude. He^+ was never found to be present in a greater concentration than a few percent. Some O^{++} was still found near 2,000 km, and Friedman noted that this is reasonable, since this constituent should have twice the scale height exhibited by O^+.

T. E. Van Zandt (U.S.A.) then reviewed the information currently available on the profile of ion composition versus height over the last sunspot cycle. This was summarized in a slide showing that He^+ virtually disappeared about 1963, when the He^+ sphere was located from 600 to 800 km high. Since that time, the O^+/H^+ transition height seems to have been rising. Van Zandt hypothesized that the reason for this behavior may be that the solar-cycle dependence of the various ionizing radiations may well involve some (solar-cycle) phase variation.

D. T. Farley (U.S.A.) exhibited two slides showing the diurnal variation of the ion composition over Jicamarca. The contours of a fixed percentage of O^+ bulge upward and reach a sharp maximum at about 1700 to 1800 hours in summer, whereas in winter the curve is broadened considerably.

H. Carlson (U.S.A.) expanded on this work, already described in this session by Gordon, on the conjugate coupling between hemispheres introduced by the photoelectrons. He noted that such coupling has been observed both at Arecibo and at Nançay, but not at Millstone. He argued that this coupling is an important influence on the heat balance at latitudes where the coupling occurs. He also suggested that observations of the 6,300-Å air-glow might well be used to extend the geographic information on this effect, since predawn heating of the ionosphere is implied under certain conditions.

Willmore opened the second half of the session with a review of the various physical processes known to affect the electron-density structure of the F region. He described the influence of the ambient magnetic field which leads to various anomalous variations of mean electron density. He summarized the effects of the solar-ionizing radiations, thermal influences, diffusive equilibrium tendencies, etc., and concluded that one must look further for explanations to describe the F-region behavior. He talked about the various large- and medium-scale field-aligned structures indicated by traveling patches of enhanced or reduced density, by the magnetospheric hf ducts, etc. Since the solar wind is likely to be a major source of energy input to the ionosphere, one must look for the mechanisms of coupling between the magnetosphere and the ionosphere. Among these mechanisms, one must consider: (1) the influence of trapped electrons with energies around 1 keV, (2) electric fields, (3) thermal conduction, and (4) diffusion. The important linkages for these four are generally along the magnetic-field lines.

Willmore described a number of attempts that have been made to provide a theoretical basis for the magnetosphere-ionosphere coupling. He noted that a number of very reasonable mechanisms do not appear to have as much influence as might be supposed. For example, Bowhill and Geisler worked out the probable effects of a heat flow from or to the magnetosphere. Unfortunately, the correlation between electron density and ion temperature seems to be reversed in sign, relative to these predictions, so that the electron density may, in fact, turn out to have the primary influence.

Willmore also noted that the presence of O^+ at great heights is not well understood, in view of currently held interpretations of laboratory data on rate coefficients. He concluded that dynamic processes must be more important than is generally recognized at present. He pointed out three possible dynamic mechanisms for moving ionization along the magnetic field, and noted that none of the three is well understood at present. These three mechanisms are: (1) influence of any neutral wind, (2) electric fields (on the order of 10^{-4} V/m), and (3) fluctuations in neutral density.

W. Calvert (U.S.A.) described some observations of ducting of hf waves from the Explorer 20 topside sounder. The effects can be observed when the sounder is located within the duct by reflection, either from the nearby ionosphere or from the conjugate hemisphere. Sometimes, a combination of the two is possible. In addition, there is evidence that the waves can be coupled into the ducts when the satellite is merely near a duct. Ducts are observed with about equal probability at all geomagnetic latitudes less than about 60° and more than a few degrees from the equator. There is a strong diurnal peak within 2 h of 0600, local time, and little activity through the remainder of the day. The horizontal scale (N-S) of the ducts, as seen near a 1,000 km height, seems to be in the range of 2 to 10 km.

Du Castel (France) described some ground-based observations of ducting on a transmission path from France to South Africa ($L = 1.75$). Pulses were transmitted at a frequency of about 9 MHz. By comparing the pulse transmission delay of the presumably ducted pulse with that of the pulse transmitted by the usual subionospheric path, it was concluded that the ducting occurred at about $L = 1.6$. Various attempts to correlate the ducted transmissions with geomagnetic time of day, season, etc., were made, but no clear pattern developed. Du Castel also described briefly an experiment in which moving ionospheric irregularities were observed by combining, simultaneously, the ionosonde measurements from an extensive ground network, from an aircraft, and from a satellite. Some irregularities were found to extend up to 1,000 km in latitude and more than 2,000 km in longitude. Motion was generally toward the equator at a speed of about 300 km/h. Evidence was found for a magnetic-field-aligned structure and for a difference in characteristics separated in latitude by a transition region at about 60°. The irregularities were smaller and more complex north of this transition.

J. A. Thomas (Australia) described some work of Dyson in Australia related to hf ducting, as seen from the topside sounder satellites. Ray-tracing analysis was performed for various duct models to determine how the waves might be coupled into a duct from a satellite located slightly outside the duct itself. The results should permit some estimates to be made of duct widths and lifetimes, with the use of successive ionograms. No experimental conclusions are yet available from this study.

E. Woyk (Czechoslovakia) summarized some work she had done on the influence of geomagnetically trapped particles on the ionosphere. The conclusions are rather detailed for this summary of the meeting, but may be found in her paper in Radio Science, 69D, March 1965, 453-457.

Van Zandt commented on a possible source of spread-F irregularities. He noted that at low and middle latitudes, hf ducts are always present when spread F is present (as seen from the Explorer 20 topside sounder). He conjectured that, by analogy with turbulence, fluctuation energy associated with the large-scale ducts may well be fed into the smaller scale irregularities. From a comparison of topside and bottomside soundings, he concluded that the majority of mid-latitude spread F is associated with hf ducts.

Gledhill (South Africa) reported on a comparison of data on ionospheric $h'F_2$ and f_{min} with electron flux data taken from Alouette 1. He found that, above some threshold electron flux, an ionospheric disturbance is invariably produced. The magnitude of the threshold flux depended upon the location of the ionosonde used in the comparison. He noted that the observed disturbances are consistent with an interpetation that the precipitating electrons heat the F region and increase the D- on E-region collision frequencies.

Dynamics of the Ionosphere Over-all Picture and E Region in Particular

CHAIRMAN: J. H. CHAPMAN (CANADA)

IONOSPHERIC DYNAMICS, WITH EMPHASIS ON THE E REGION

C. O. Hines (U.S.A.)

A general circulation similar to that of the lower atmosphere is imposed on the neutral gas of the upper atmosphere. The macroscopic dynamical processes are initiated by energy deposited in the gas. The circulation has prevailing horizontal winds of some strength and small but important vertical transport. It is subject to seasonal changes and to shorter term modulations, with the passage of pressure systems. It is of a typically meteorological character up to heights of 110 to 120 km, but there it becomes modified by electrodynamic forces imposed through ion-neutral collisions. These forces grow in importance with height because of the density change and may even become dominant above 150 to 200 km. They change diurnally, along with the change of ion concentration resulting from solar-energy insolation. The combination can give rise to an intricately interacting system, resulting in tide-like components in the neutral-gas motion.

True hydrodynamic tides are generated principally in the troposphere and ozonosphere. They propagate upward into the E region, increasing in amplitude as they progress, until severe dissipation leads to a decrease of amplitude once again. As with the general circulation, the tidal oscillations become subject to a substantial hydromagnetic influence above 110 km or so; by the

time the top of the E region is reached, they are predominantly hydromagnetic in nature, and they retain this characteristic at all overlying levels. With the diurnal change of ion concentration, they can generate apparently prevailing components of wind.

Shorter period internal-gravity waves, close relatives of the tides, propagate upward into the E region from sources near its base and below, and they produce wind amplitudes comparable, on occasion, to those of the tides. They embrace a broad spectrum at the lower elevations, and so give rise there to noise-like irregular wind variations. The spectrum is attenuated and narrowed by reflection and dissipation as the energy proceeds upward, and the wind profiles accordingly become smoother. Evanescent gravity waves are also present, though their observational significance has yet to be established with equal weight.

Hydrodynamic turbulence of a conventional type persists to elevations of 100 to 110 km, but there it subsides; it has not been detected at higher levels. Its motion can reveal the background winds that transport that turbulence.

Ions are transported, more or less, with the neutral gas to heights of 110 to 120 km and even higher, when only the magnetically aligned component of velocity is considered. Their motions, transverse to the geomagnetic field, are subject to an increasing hydromagnetic control at greater altitudes, however, and are constrained to follow equipotentials of the pertinent quasistatic electric fields above 150 to 200 km. Residual deviations from the neutral-gas flow can be important even at the base of the E region, particularly in the presence of the strongly shearing winds introduced by tides and internal-gravity waves, to the extent that sporadic-E sheets may be formed. Lesser modulations of the ion distribution are created by the general assemblage of gravity waves and give the appearance of movement as those waves progress. The wave spectrum that escapes to the F region, while energetically weaker, gives rise to traveling disturbances that have been detected to heights of 700 km.

Discussion

Spizzichino (France): E-W components of winds at 80 to 120 km were studied by means of three different radio systems, a forward-scatter link, a vertical ionosonde at the midpoint of the path, and a bistatic meteoric radar. Results: Ten to fifty measurements per hour were made with ±1-km altitude resolution. A strong eastward

component, amounting to 60 m/sec, was observed around sunrise. The variation over a few hours at different altitudes indicates a downward motion of the pattern of 1 to 10 km/h. Semidiurnal and diurnal tides were recognized.

Haubert (France): The pattern of amplitude changes derived from a pulsed transmitter and 36 receiving antennas contained in a 150 m^2 area was studied. Amplitude changes were shown as intensity dots or squares on a cathode-ray tube and were photographed as a function of time. Film patterns showed: (1) steady ionospheric reflections (all antennas); (2) patterns, starting with an increase or decrease at some dipole element, moving away from the initial point in a form similar to an implosion or explosion; and (3) patterns of crests or troughs sweeping across the cathode-ray tube presentation.

Sprenger (Germany): Transmissions at various frequencies, from 129 to 272 kc/sec, were received at two stations. Wind (drift) motions were derived by comparisons of the data. The measurements continued for 10 years. Comparisons with meteoric-drift measurements at Jodrell Bank were made. There was found to be a prevailing drift E or SE in winter and summer, superimposed by a strong semidiurnal drift component rotating in a clockwise direction. Transitional periods in spring and fall, with drift directed SW, were accompanied by a phase shift of the semidiurnal component. Sunspot-cycle dependence was toward sunspot minimum, and the prevailing wind decreased while the semidiurnal component increased.

Haser (Germany): Films of rocket-released barium trails have been made. Several heights were used on the same rocket. Ion clouds were observed up to a height of 2,000 km. It was found that the ionized part of the cloud gave off distinctive colors identifying the reaction; part of the cloud remained neutral. The ionized cloud dissipated along the magnetic-field line, while the center of the neutral cloud expanded away from the center of the ionized elongated patch. Three measurements at 130 to 400 km gave neutral-wind direction and speed, information on electric fields, and the geometry of the geomagnetic field. Sardinia tests found a neutral wind (moving at 50 to 100 m/sec) changing direction during the course of a day. The ion cloud moved more slowly than the neutral cloud. The electric field was deduced to be 1 to 3 mV/m,

and pointed north in the morning and south in the evening. Churchill tests showed an ion cloud, perpendicular to the magnetic field, moving west in the evening and east in the morning. One ion cloud remained straight for 0.5 h, extending for 2,000 km. No fine structure of 20 km or higher was found.

Pfister: Harnischmacher has observed diffraction patterns from a system of six antennas arranged in a double-triangle array, one wavelength apart. Curved patterns were obtained by combining the intensity variations at all antennas. Curvatures which could be concave or convex, occurred 15 to 20 percent of the time. A new fading experiment giving amplitude and phase correlations is now in operation near Boston. The different antennas show differences in phase of multiples of 2π.

Hines: 1. In half the cases, wind measurements made by means of vapor trails gave the same results as drift measurements above the turbopause (105 km). This is explained as a consequence of irregularities (large vertical oscillations) that arise when the velocity of some gravity wave, out of a family of gravity waves, matches the background-wind velocity.

2. Two traveling disturbances observed by Thome at Arecibo were analyzed on the basis of gravity-wave theory. An upturning of the phase front at high levels appeared to be a consequence of dissipation processes. Certain differences in the phase and amplitude behavior of the two cases were accounted for by the theory referring to neutral gas. There was no geomagnetic storm at the time of observation.

Ratcliffe: Spaced-receiver techniques should have antennas spaced at not less than a half wavelength. At 10-wavelength spacing, different things might be happening. One should look at information theory, as present techniques may give redundant information.

Bibl: If one does not understand the pattern at one wavelength, one cannot understand the pattern at more widely spaced distances.

Bowhill: The fine structure of sporadic E has been studied with a rocket sensor, with simultaneous measurements from a ground-based ionosonde being made. Results: The rocket showed small (about 25-m) irregularities in the bottom slope of the E_s profile. The ionosonde gave a critical frequency of 3 Mc—too high for

specular reflection at the vertex of the larger slope—thus indicating return by scatter, in accordance with the observed fine structure. He suggested that a detailed analysis of nonblanketing E_s from ionosonde measurements could be used to measure irregularities in E_s from 90 to 100 km.

Friedman (U.S.A.): Ion constituents of the E region have been observed by means of a rocket spectrograph. In a sample through a strong sporadic-E patch at sunset, three layers existed: (1) 106.5 km, 2 km thick of Mg^+ and Fe^+ only; (2) 114 km, Mg^+, Fe^+, and much less NO^+; and (3) 122 km, NO^+ only. The layer at 122 km was weaker in electron density. These were strongly stratified layers, the lower ones composed of meteoric material. There is evidence that the meteoric ions persist for a long time. The layer at 106.5 km built up in a few minutes.

Toman (U.S.A.): WWV propagation, with the use of the Doppler effect on the carrier and on a sideband, has been studied to deduce phase-path and group-path shifts. Results: In an auroral precipitation event, the usual sunrise change in phase path was preceded by phase variations corresponding to a disturbance traveling southward at 340 m/sec, at heights from 270 to 240 km. When extrapolated back to the auroral zone, there was a coincidence in time with an absorption event at Great Whale. This raises the question: assuming that conversion of energy took place, what were the height and the mechanism of the conversion process?

Hines: He believes that energy was converted at 100 to 150 km and traveled principally in the horizontal direction at those levels. The observations at higher levels simply reveal the upward extension of the disturbance in evanescent form, but do not indicate the presence of a substantial fraction of the energy there.

King, G. A. M. (New Zealand): A. G. French has observed an event, similar to Toman's, traveling at 900 to 1,000 m/sec. He used auroral observations over the Antarctic. French suggests that an auroral form moving over a large area at a velocity many times that of sound may act as a heat source sending out a bow (shock) wave.

Klostermeyer (Germany): Gravity waves at F-region heights

have been studied with the use of ionosondes at three stations separated by 100 km. Quiet winter nights were chosen, to avoid electrodynamic effects. Height variations were normalized. Periods of 0.7 h to several hours were observed. Plots of velocity versus direction were shown. Maximum velocity was obtained for propagation toward the south. He showed plots of periodic component of height variation in kilometers versus time of the day.

Becker (Germany): 1. Lunar tidal effects on the F layer in undisturbed periods ($k_p \leq 3$) were studied for two years, with the use of ionosonde data. Results: A chart shows the variations with lunar phase. The amplitudes of various quantities were: peak height, 0.9 km; critical frequency, 0.6 percent; relative variation and thickness parameter, 1.4 percent.

2. Height displacements of the F_2 layer, supposedly caused by electrodynamic drifts, were studied. The seasonal variation of F-region height shows two maxima and two minima, whereas the thickness parameter has one maximum and one minimum, following closely the product of 10-cm flux and the cosine of the solar-elevation angle.

Hines: Upward motion of layer profile may not mean an ionization change in the same direction, as implied by Becker. In fact, the Arecibo facility detected downward motion of ionization irregularities, in the trough between the E and F layers, at times when the F-layer profile was moving upward.

Cohen (U.S.A.): Neutral winds in the equatorial electrojet were determined from Doppler measurements at an ionospheric-scatter radar. It was found that radar scattering at irregularities of the electron concentration in the electrojet reveal periodic variations of the Doppler effect, with periods of about one hour. These variations are attributed to periodic changes of the neutral-wind velocity, in which the ions take part. Only E-W components could be observed.

Ratcliffe: Considerable differences in reception by two ground-based antennas separated by less than one-half wavelength might indicate radiation from surrounding structures on the ground. Free-space conditions do not apply in this case. Attention should consequently be paid to ground effects.

Piggott: In slowly varying conditions, the diffraction pattern on the ground should be rather smooth, but rapid fading can cause a small-scale structure observable on two closely spaced antennas.

Becker (Germany): Satellite-track measurements are frequently based on the assumption that temperature and composition remain constant; however, both are found to change. This is a source of errors.

Hines: It is important to study the seasonal changes in the turbopause. The height and the types of constituents should be determined in their dependence on latitude.

COMMISSION III / SESSION OF SEPTEMBER 13 (A.M.)

Dynamics of the Ionosphere F-Region Phenomena: Interactions Between Movements of Neutral Atmosphere and Ionosphere

CHAIRMAN: K. MAEDA (JAPAN)

REVIEW PAPER

H. Kohl (Germany) and J. W. King (U.K.)

The horizontal movement of the wind at 300 km, the global circulation, has been computed from the pressure gradients in Jacchia's model atmosphere, taking into account Coriolis, inertia, viscous, gravitational and ion-drag forces, but omitting any motion of the neutral atmosphere produced by ions in motion. The motion of the wind across the magnetic-field lines raises or lowers the ionization present, depending on the orientations of the wind vector and the magnetic vector. The electron-loss rates are altered by the change in height; therefore, the distribution of the electron density in time, in height, and in latitude will be altered by the global circulation.

The wind calculations depend markedly on the ion-drag term, its effect being an order of magnitude stronger than the Coriolis term. The wind, then, has a strong dependence on the ion density; the effect of the ions is to produce nongeostrophic wind patterns.

For the theoreticians, there remains the problem of combining, with the forces taken into account above, the force on the neutral atmosphere exerted by the motion of the ions produced by all sources.

The winds deduced have speeds of the order of 35 or 100 m/sec for the peak densities of 10^6 and 3×10^5 electrons cm^{-3}, and move generally from the hot spot (delayed about 4 h from the subsolar point) to the cool spot (the antipole of the hot spot). The circulation

follows great-circle routes when the peak electron density is 10^6 cm^{-3}, and is modified principally by the Coriolis force when the electron density is 3×10^5 cm^{-3}.

While the neutral wind computed is horizontal, the main effect on the ionization is a vertical motion, and this motion is suggested as the explanation of certain anomalies in the F region; in particular, the midday bite-out, the UT effect at high latitudes, and some features of the maintenance of the nighttime F region. Certain features of the neutral upper atmosphere, that have been explained in terms of an "additional heat source," may well be a consequence of the computed circulation.

It is clear that the computed circulation contributes to the observed characteristics of the ionized and the neutral upper atmosphere and that the ion-drag term is an essential in any estimate of upper-atmosphere dynamics. In particular, the seasonal anomaly and the equatorial anomaly are not likely to be explained without accounting for the effects of the global wind.

In middle latitudes, wind drifts have a downward component from 0800 to 2000, local time, and upward component from 2000 to 0800.

Du Castel: He reported on the results of equatorial observations made simultaneously by ground-based ionosondes, an ionosonde in an aircraft, and the soundings of the Alouette satellite. The aircraft observations were made along a magnetic meridian and included the periods from March 20 to April 10, 1965, and from June 21 to July 12, 1965. The measurements made it possible to derive electron densities in the vertical plane in the magnetic meridian for a distance of approximately 15° north and south of the geomagnetic equator.

Three zones of ionization were distinguished:

1. An upper zone, above the contour of electron density, was
171 equal to 3.5×10^5 cm^{-3}. This had a symmetrical structure about the geomagnetic equator and is consistent with a diffusive equilibrium process.

2. A lower zone, below 200 km, where production and recombination dominate, approximately as given by spectrochemical equilibrium.

3. A middle zone, containing the ionization masima, which appeared to be heavily influenced by heating processes.

Evans (U.S.A.): The seasonal anomaly may be caused by changes in

the loss coefficient β. These changes, in turn, could be due either to temperature changes or to changes in the neutral constituents. Satellite-drag data indicate that the neutral temperatures are similar in summer and in winter. However, this still leaves the possibility that the ion temperatures behave differently. Measurements at Millstone over two years have shown no significant variation with season. Thus, the temperature effect is ruled out. At present, Evans is trying to establish the variations in relative abundance of heavy ions, compared with lighter ions.

W. Becker (Germany): He showed 27-day running averages of the height (hm) of the F_2 peak and the half-layer thickness (ym) of a parabolic fit to the F_2 layer, during a year of high and a year of low solar activity. The value of hm was shown to be closely correlated with $\phi \cos \chi$, where ϕ is the 10.7-cm solar flux, and χ is the solar-zenith angle. During the year of high solar activity, hm was negatively correlated with $\phi \cos \chi$ in the summer months. It was concluded that this can only be due to a downward drift of the ionospheric plasma to lower levels. It was further concluded that the seasonal f_oF_2 anomaly of the mid-latitude ionosphere is due primarily to increased attachment losses, rather than to changes in the percentage of molecular nitrogen.

From 27-day running averages of the subpeak total electron content, it was shown that the seasonal anomaly vanishes with decreasing solar activity. This is explained if the decrease in f_oF_2 values in summer, at sunspot minimum, is due mainly to the temperature increase (expansion effect), which does not affect the total electron content.

Maeda (Japan): He said that, if it is found that the electromagnetic drift effects are the important factors in explaining the equatorial anomaly, then such drift effects may also be important at mid-latitudes. To obtain the necessary results, one must first obtain the electric field.

S. Matsushita (U.S.A.): He continued the remarks of Maeda by describing methods for estimating the electric fields resulting from the dynamo action. He showed the S_q current systems, as they were observed during sunspot maximum. Since the coefficients of the expansion for the current are related to sunspot number, it is possible to calculate the current for any position and sunspot number. From drift measurements and from an atmospheric model, the electric field can be calculated.

H. Poeverlein (U.S.A.): He discussed the electrodynamic drift of plasma descending from the magnetosphere. The drift results from the co-rotation of the magnetosphere with the earth and from the deformation of the magnetosphere by the solar wind. It is postulated that the rotation takes place about the force lines, ending at the neutral points on the magnetosphere boundary. The vertical plasma motions continue down to ionospheric heights and cause plasma density variations and vertical velocities of the order of 20 m/sec.

Dynamics of the Ionosphere F-Region Phenomena: Interactions Between Movements of Neutral Atmosphere and Ionosphere (cont'd)

CHAIRMAN: C. O. HINES (U.S.A.)

This session was a continuation of the morning session on F-region dynamics. The discussion was concerned primarily with the seasonal and equatorial anomalies and with the mechanism responsible for maintenance of the nighttime ionization.

The "seasonal anomaly" refers to the fact that f_oF_2 is higher in winter than in summer. The "equatorial anomaly" refers to the fact that f_oF_2 exhibits not more than a few degrees on either side of the magnetic equator. Both of these anomalies, as well as the fact that f_oF_2 often increases during the night, are definite evidence that the F_2 region is controlled by more complex mechanisms than simple changes in solar illumination.

King contended that the seasonal anomaly probably results from a change in the loss rate of ionization. He arrived at this conclusion after examining the behavior of the F_1 layer, where the change in recombination rate predominates. At F_1 heights, the recombination rate is six times greater in summer than in winter and, at high latitudes, it exhibits an abrupt seasonal change coincident with stratospheric warming in the Antarctic. Presumably, the change in recombination rate results from a change in molecular content. At F_2 heights, the change is similar, though less prominent.

Ratcliffe discussed the geometry of the equatorial anomaly. He pointed out that the very existence of this arch-shaped region of enhanced ionization could explain the so-called $F_{1.5}$ layer frequently seen at near-equatorial stations. The extra cusp on the

ionogram results from a very slight inflection of the vertical ionization profile at the inner boundary of the arch. A similar cusp is frequently seen on topside ionograms. These cusps should be useful as indicators of the exact position of the anomaly and might, for example, permit detection of small lunar effects. In this connection, G. H. Munro cautioned that off-angle reflections might occasionally confuse the interpretation of the ionograms.

Du Castel confirmed Ratcliffe's statement that the $F_{1.5}$ layer occurs only on the equatorward side of the ionization peak.

Generally speaking, the E region, in contrast to the F region, is under solar control. At times, however, the vertical movements in the F region may produce disturbances in the E region as well. F. H. Hibberd (Australia) displayed evidence that the exponent n in the relationship

$$\cos \chi = k\,(f_oE)^n$$

exhibits mid-latitude peaks around noon, whose exact positions seem to depend on the S_q current.

Brown presented evidence that vertical movements affect the E and F_1 layers, not only when they are under the control of S_q currents, but also in response to the local-time component of the disturbance variation Ds and to the storm-time variation. At noon, the time of maximum vertical drift due to S_q, f_oE, and f_oF_1 are correlated with Ds, and f_oE shows a depression, as does the magnetic field, following geomagnetic storms.

Nisbet (U.S.A.) presented evidence from Arecibo that large day-to-day variations in N_m are inversely related to T_e. Ratcliffe cautioned against the use of single stations to draw such a conclusion, and he was supported by Bibl, who showed examples of drastic anomalies at neighboring stations.

King discussed the relative effectiveness of two causes of F-region variability, viz., the mixing effect of electrodynamic forces, and changes in recombination rate. The former is effective in increasing f_oF_2 but less effective in reducing it, while recombination is responsible for sudden decreases. He suggested that the recombination rate increases suddenly when waves caused by magnetic-storm activity become nonlinear and break, changing the turbulent structure of the medium. These waves are effective in transporting storm energy from the auroral zone toward the equator.

Petit (France) described the interpretation of incoherent-backscatter measurements made in France. He pointed out that the power spectrum of the echo depends on both T_e/T_i and the composition, but that these cannot be separated clearly. Supplementary rocket measurements have been helpful in disentangling the two. Evans felt that it was dangerous to use rocket measurements, which correspond only to a single time and place and suggested, instead, measuring T_e/T_i at heights where only O^+ is present. Fejer (U.S.A.) asked whether the spectrum of the echo is symmetrical and speculated that if it were not, it might contain information about vertical drifts. Petit stated that such Doppler effects are too small to observe.

Rüster (Germany) described numerical-model calculations from which he deduced that electrodynamic forces are, in the ionosphere, quite effective in producing neutral winds.

Evans described incoherent-backscatter observations from Millstone which show T_e to be much higher on winter nights than on summer nights. As to the source of heat, he pointed out that enough heat exists in the protonosphere to sustain the difference between T_e and T_i, and suggested that increases in total electron content at night are caused by a lowering of temperature at sunset and a consequent draining of electrons down from the exosphere.

Stubbe (Germany) described an extensive set of numerical model-fitting calculations involving electron loss, diffusion, flux from the protonosphere, winds, and vertical drift caused by N-S motion of neutral air. He concluded that satisfactory fits to observations can be made by using laboratory measurements of the recombination coefficients, but that a flux of about 1.8×10^9 electrons cm^{-3} sec^{-1} is required to explain the observed nighttime f_oF_2. The most effective drift motion appeared to be a W-E transport of plasma caused by an electric field in the N-S direction.

Van Zandt showed examples of observations of the 6,300-Å airglow, as seen from Hawaii. He asserted that the well-established correlation between red-line airglow intensity and the height and electron density of the F region makes this an effective way to observe medium-scale F-region structure. He showed examples of intense structures with horizontal scales of about 500 km moving at velocities of 150 to 200 km/h.

COMMISSION III / SESSION OF SEPTEMBER 13 (P.M.)

Second Business Meeting

CHAIRMAN: J. A. RATCLIFFE

It was announced that, subject to final confirmation by the Assembly, the new Chairman will be Dr. Hines; the new Vice-Chairman, Dr. Rawer.

Working Group Reports

a. W. R. Piggott (Topside Nomenclature; Ducting). The working group agreed on the desirability of an internationally agreed topside nomenclature based on Canadian usage. It recommended that the letter "H" be used for determinations of local plasma density from the transverse resonance f_T and the gyrofrequency f_H. Usage should be uniform with bottomside usage. The report was adopted.

On a CCIR question concerning ducting, the working party recommended that a small continuing working party be set up to consider the question further and more thoroughly. The Chairman thought that this should be closely attached to the URSI/CIG Committee. This was agreed upon.

b. A. H. Shapley (Omnibus Working Group).

Draft Resolution 1. This was agreed upon.

Draft Resolution 2. Ratcliffe asked if this could be condensed. It was decided to send a redrafted document to CCIR and to recommend item G as part of the resolution.

Draft Resolution 3. On the establishment of a continuing working group on sounding stations. It was agreed upon.

Draft Resolution 4. To be enclosed as the annex to a brief resolution. This was agreed upon. Dr. Whitehead (Australia) will be asked to prepare a detailed answer to the CCIR questions (to be cleared with Professor Webster first).

Draft Resolution 5. This notes the interest in a compilation of a reference ionosphere, but it points out that all the important variables must be included and asks for a working group to be set up to both study the need for a reference ionosphere and determine the practicability of providing one. Dr. Bowhill was suggested as convener. This was agreed upon.

c. R. Wright (Drifts). Five interim suggestions were made on how data should be analyzed for the time being because no definitive agreement could be obtained:

1. "Similar fade" technique to be a standard;
2. Several more stations to be set up;
3. Intercomparisons to be made between methods;
4. Original data to be kept for later reanalysis; and
5. Study to continue of analysis techniques and physical significance.

Recommended: that a working party be set up under URSI/CIG.

Recommended: that a symposium be arranged on ionospheric drifts, with particular emphasis on the physical significance. Two separate resolutions will be made. This was agreed upon.

d. K. Rawer (Absorption). Fifteen persons attended the working-group session. A resolution was drafted on vertical-incidence pulse techniques, etc. Preparation of new operators' manuals was requested, no working party would be needed. This was agreed upon.

On the Rawer-CCIR question on mechanisms that produce fading, it was recommended that a working group answer the question by correspondence. It was agreed to let Rawer handle this alone and transmit his reply to CCIR.

Rawer convened the Subcommittee on Automatic-Data Handling, and a document was circulated.

e. O. Villard (Transequatorial Propagation). A response was needed to a CCIR question, but the appropriate documents could not be obtained in time. Villard suggested setting up a working group, to be limited to a life of one year and to work by correspondence. This was agreed upon. (Reporter's note: Since the documents to which the above reports referred were not available at the meeting, only a sketchy report could be given.)

When the reports were completed, Commission III passed a hearty vote of thanks to the outgoing Chairman, J. A. Ratcliffe.

New Topics

CHAIRMAN: J. A. RATCLIFFE

AVERAGE-ELECTRON PROFILE

Dr. Becker (Germany)

For radiowave-prediction purposes, simple models are required. Becker's model is based on true-height data for Landau, Germany. In order to describe average conditions, normalized values (non-dimensional parameters) were derived. The electron distribution as a function of height was expressed in N/N_e, where N_e is the electron concentration at the F_2 peak. The second parameter is $(h_m - h)/y_m$, where h_m represents the heights of the F_2 peak and y_m represents the half-thickness of a parabolic distribution for the F_2 layer peak area.

Noon and midnight values are derived for the four seasons and for the high- and low-sunspot years. The electron distribution at noon shows the influence of the F_1 layer during the summer; otherwise, the distribution behaves normally. At midnight, little change occurs in the course of the year.

The layer thickness parameter $(h_m - h)y_m$ shows no seasonal variation between the values 0 (layer peak) and 0.5; for larger values, seasonal variations appear.

The thickness parameter varies proportionately to the solar flux at 10 cm.

N67-16006

COMMISSION IV

MAGNETOSPHERE

CHAIRMAN: PROF. H.G. BOOKER (U.S.A.)

Organizational Meeting

CHAIRMAN: PROF. H. G. BOOKER (U.S.A.)

A preparatory organizational meeting of Commission IV was held with the following officers present:

Chairman:	Prof. H. G. Booker
English-speaking Secretary:	Mr. H. E. Dinger (U.S.A.)
French-speaking Secretary:	Prof. A. L. Delloue (France)
Scientific Editor:	Mr. Fred Horner (U.K.)

The main purpose of this meeting was to confirm the designation of chairmen and reporters for the various technical sessions. The list was subsequently duplicated and distributed.

Prof. Booker asked Prof. Helliwell (U.S.A.), Dr. Kimpara (Japan), Prof. Rivault (France), and Mr. Horner to prepare an organizational proposal for future work in the fields covered by the present Commission IV and its subcommission (Commission IVa) and to submit a report to the second organizational meeting scheduled for September 7.

General Business

CHAIRMAN: H. G. BOOKER

The following voting members were present: Webster (Australia); Ungstrup (Denmark); Rivault (France); Elwent (Germany); Veldkamp (Netherlands); Burtt (New Zealand); Clarence (S. Africa); Dungey (U.K.); Likhter (U.S.S.R.); Johnson (U.S.A.); and Nagata (Japan).

After covering a number of routine matters, the meeting turned to discussion of the organization of the remaining Commission IV sessions. The main topic was the session on New Developments. A tentative agenda was read and accepted with the addition of three topics offered from the floor. A conflict of the New Developments session with a concurrent Commission III session was noted. Eventually, it was agreed that the time had passed when any improvement could be made.

The next issue discussed was the report of a working party appointed to consider terms of reference of the present Commission IVa on Radio Noise of Terrestrial Origin. The working party recommended establishing a new commission on this subject and set forth a list of six recommended terms of reference for the proposed new commission (Working Party Report, Appendix I). Also appended to the documents of the working party is a memorandum on the scopes of Commission III, Commission IV, and the proposed new commission. After some discussion, it appeared that there was general agreement on the substance of these documents and disagreement only on details which could easily be resolved later. Because they will be of wide interest in the United States, the pertinent documents appear above in the "Working Party Reports" section preceding the various commission meeting reports.

Dr. Kimpara will very probably be designated chairman of the new commission if it is established by the Executive Committee.

The meeting then turned to the subject of the Subcommission on Synoptic Whistler Observations. It was agreed that the subcommission should be continued for the next triennium. A brief business session of the subcommission was scheduled.

The Chairman revealed that commission recommendations to the Executive Committee regarding new officers of Commission IV for the next triennium would be needed within a few hours. After a discussion of relevant protocol, the meeting turned to the selection of candidates. The recommendations were:

Chairman:	H. G. Booker
Vice-Chairman:	J. W. Dungey (who will probably be named Chairman to succeed Booker three years from now)
English-speaking Secretary:	F. S. Johnson
French-speaking Secretary:	A. L. Delloue
Scientific Editor:	N. Clarence

Dr. Kimpara was recommended as Chairman of Commission IVa, should the Executive Committee decide to retain the present structure. If the new commission comes into existence, then, with the new commission, it will share an interest in the Subcommission on Synoptic Whistler Observations. Commission IV recommends that G. McK. Allcock represent it on the subcommission as either Chairman or Vice-Chairman.

Next, there was a discussion of possible URSI participation in an international symposium on magnetospheric physics, to be held in 1968 in Washington, D.C., under the primary sponsorship of NASA. It was learned that IUGG is apparently prepared to support the symposium. There was a discussion of the possible relationship with one of the proposed symposia to be held in conjunction with the COSPAR assembly of 1968 in Japan. It was agreed that Commission IV would recommend to the Executive Committee that action be taken to give URSI support to the Washington symposium.

A CCIR document was read noting a need for information on the characteristics of noise received aboard spacecraft from a variety of terrestrial, solar-system, and extra-solar-system sources. This implied a request that URSI give attention to this topic, and

a subcommittee (Booker, Christiansen of Commission V, Helliwell, Kimpara) was appointed to make recommendations.

The meeting closed with comments from the URSI Commission IV Editor, F. Horner, on session reporting. Another business meeting was scheduled for September 14.

Atmospherics I: Characteristics of Atmosphere at the Source and Propagation

CHAIRMAN: PROF. H. G. BOOKER

REVIEW PAPER

E. T. Pierce (U.S.A.)

Digital methods as well as analog methods have been used to obtain the well-known spectra showing peaks around 8, 14, 20, and 26 Hz. The use of places with low noise of man-made origin enables the higher harmonics to be obtained.

When recorded on magnetic-loop antennas, the spectra never exhibit a second harmonic with a level higher than the first. The use of two orthogonal magnetic components and the comparison between the records obtained at two distant stations make it possible to ascertain that the diurnal-amplitude variation of the resonance is due to geometrical factors, relating the position and direction of the sources with respect to the receiving magnetic coils. However, a strong absorption near 1400 to 1700 hours, local time, for N-S propagation must be taken into account.

The interpretation of diurnal variations of both amplitude and frequency has been achieved by introducing an equivalent electrical network covering the earth. The parameters of this network (conductivity of the ionosphere and inclination and intensity of the magnetic field) can be adjusted to include both the day - night asymmetry and the effects of ionospheric events, such as polar-cap absorption (PCA), sudden ionospheric disturbance (SID), etc. It is thus hoped that the Schumann resonances can be used as a tool for immediate detection of ionospheric disturbances of worldwide importance.

Discussion

In response to a question by Horner, Pierce indicated that, in preparing a table of normalized values of field strength amplitude, he (Pierce) had assumed that amplitude was proportional to bandwidth at vlf and proportional to the square root of bandwidth at hf. Horner indicated that there is as yet only vague evidence that the vlf/hf ratio of lightning energy is greater in the tropics. Reviewing eight years of data from lightning-flash counters, he reported a relation $\log N \propto T$ for Slough, and $\log N \propto T^2$ for Singapore (N is the monthly flash count, T is the number of thunderstorm days in a month). The peak of activity at Slough is at 1600 hours, and, at Singapore, 1800 hours, with a subsidiary peak in the early morning hours.

R. Gendrin (France) reviewed recent work on elf cavity-resonance phenomena.

H. Volland (Germany) described methods used by Heydt and himself to obtain information from a single station on the number of discharges, magnitude and phase of the propagation function, and the amplitude and phase spectrum of atmospherics. The method is valid up to 4,000 km and is particularly useful in resolving the behavior of two thuderstorm centers located at different distances on the same azimuth.

Rycroft (U.K.) pointed out a puzzling feature of his results on the spectrum of the vertical electric field at elf; namely, an unexplained background level of energy. Gendrin remarked that the true noise level is difficult to determine.

Webster showed frequency-time spectra of elf recordings at Brisbane, some 3,000 km from a thunderstorm source. He also showed a record indicating a diurnal maximum of 8 Hz activity near 6 a.m., with another peak late in the day.

Pierce (U.S.A.) reviewed the progress made since the last General Assembly in the study of the characteristics of atmospherics at the source and in the study of their modification by propagation effects. The location of thunderstorm areas by ground stations and satellite-borne detectors was also discussed.

With regard to the characteristics of the source, Pierce considered it now well established that, as the frequency increases above the vlf band, the peak amplitudes of the radiated pulses decrease, but the number of pulses per discharge becomes larger, reaching a value as high as 10^4 at about 50 MHz, and thereafter, a decrease in the pulse number sets in. The peak electric field of vertically polarized radiation from lightning varies approximately

inversely with frequency ($e_p \propto f^{-1}$) over the whole frequency range from about 10 kHz to 1,000 MHz, but there is evidence of wide deviation from this simple relation in limited spectral regions. An appreciable horizontal component of polarization exists even for return strokes, which are often inclined at 20° or more to the vertical.

Concerning the propagation of atmospherics, Pierce reported that, while one group of workers has found a very deep minimum of propagation attenuation at night between about 6 and 8 kHz, others have reported the minimum at a frequency in the 3- to 6-kHz range. The conclusion, that propagation depends on the orientation of the path with respect to the geomagnetic field and is best for the W-E direction, has been further confirmed. Improvement of propagation at elf caused by sudden ionospheric disturbances has also received additional confirmation.

Pierce pointed out that some latitude variation in the characteristics and occurrence of thunderstorms is now apparent, but that the subject requires further study. The relatively small amount of work that has been done on tropical thunderstorms has already yielded some surprises.

Observations of atmospheric noise in space are available as a by-product of other investigations, but most of the data are for vlf signals propagating in the whistler mode and have not yet been thoroughly analyzed. It appears, however, that satellite results are consistent with what is known about the sources and the attenuation of the waves in passing through the lower ionosphere.

The possibility of using satellite-borne detectors to locate individual thunderstorms on a global basis has been considered, but all proposals turned out to be beset with difficulties. These include the high speed of a low-orbiting satellite and the need for an elaborate antenna system for a synchronous satellite. If the signals are received in the whistler mode (as contrasted with propagation at frequencies well above the penetration frequency), additional problems arise as a result of the often controlling propagation effects.

In theoretical work, there have been additional contributions in the last three years in the derivation of amplitude and phase spectra of radiation from lightning flashes. These methods are limited because the results depend on the assumptions made about the characteristics of the stroke, but reasonable choice of parameters now leads to a fairly good agreement with experimental observations.

Whistlers

CHAIRMAN: PROF. H. G. BOOKER

RADIOELECTRIC WHISTLERS

R. Rivault (France)

Important progress has been made since 1963. Synoptic records that cover more than half a solar cycle from 1957 onward have been used to find relations between the phenomenon occurrence at various latitudes and the solar and magnetic activities. Several methods, based on the reception of whistlers or vlf-emitted signals, have been used to obtain the characteristics of the ionized paths followed by the energy and to specify its variations. Analysis of numerous knee whistlers recorded in the antarctic region has led to the discovery of the plasmapause and permitted the study of its diurnal variation. It is a boundary directly controlled by the geomagnetic field, which divides the magnetosphere into two regions: the inner one, where the electronic density N is of the order of 100 electrons per cubic centimeter, and the outer one, where N does not exceed a few electrons per cubic centimeter.

Finally, new types of whistlers, which may be interpreted as partially transverse propagation, have been recorded by the Alouette 1 satellite. These whistlers are principally protonic or ionic whistlers, whose characteristics depend on the gyrofrequency of the ions present in the surrounding plasma; and subprotonospheric whistlers, whose energy is propagated by successive reflections between the base of the ionosphere and the altitude of the satellite,

i.e., between about 100 km and 1,000 km. It is hoped that these results will contribute to a better knowledge of the magnetosphere ionic composition.

Discussion of Review Paper

Dr. D. A. Gurnett (U.S.A.) asked if the decreasing latitude cutoff in whistler occurrence with increasing K_p was for ground-observed whistlers. After an affirmative answer from Dr. Rivault, Dr. Gurnett commented that short fractional-hop whistlers in Injun 3 vlf data are observed to be abruptly cut off in latitude. This cutoff of ground whistlers may therefore occur in the hemisphere of the lightning source and between the source and approximately 500 km.

Further Discussion and Comments from Participants

I. Likhter: On the Amplitude Spectra of Whistlers. The amplitude spectra of whistlers is determined by the following factors:

1. The amplitude spectrum of the initial atmospherics.
2. The spectral characteristics of the penetration of electromagnetic waves through the ionosphere.
3. The spectral characteristics of the propagation in the magnetosphere.

Fligel (IZMIRAN) and Aksenov (IRE) have calculated the spectral characteristics of wave penetration through the ionosphere, using a WKB approximation and a combination full-wave solution - WKB approximation, respectively. These solutions agree above 1 kHz. Solelev and Likhter have analyzed the amplitude spectra of whistler signals received near Riga. Taking into account the standard spectrum radiated by lightning and propagation effects, these results were compared with the calculation of Fligel and Aksenov.

The amplitude-frequency spectra of whistlers have the following characteristics:

1. The day spectrum is wider in frequency than the night spectrum.
2. The peak amplitude occurs during the day at 3.0 to 3.5 kHz and, during the night, at 5.0 to 6.0 kHz.
3. The experimental and calculated spectra agree particularly well at night.

In future work, account is to be taken of more absorption in the earth-ionosphere waveguide to improve the theoretical day spectra.

N. Clarence: A Comparison of IGY and IQSY Synoptic Whistler Data. Whistler data from the IGY (1958-1959) and from the IQSY (1964-1965) are found to have the following significant differences:

1. Number of Whistlers Recorded. Accounting for the variation in recording periods, approximately 26 percent as many whistlers were recorded during the IGY as occurred during the IQSY. It appears unlikely that this occurrence drop could be explained by a drop in thunderstorm occurrence at the conjugate point.

2. Maximum Rate of Occurrence. Comparison of these two periods revealed that the maximum whistler rate decreased from 1/min to 2/min during the IGY, to 0.4/min to 0.6/min during the IQSY.

3. Intensity of Whistlers. On a subjective 0 to 5 intensity scale, the IGY whistlers registered 2, 3, and 4, and the IQSY whistlers, 0, 1, and 2.

4. Diurnal Occurrence. Of the whistlers observed, only 10 percent occurred in the IGY during daytime (0600 to 1800 hours, local time) but 53 percent occurred in the IQSY during daytime. This effect is probably explained by D-region absorption, because the absorption at 1.83 MHz decreased from 60 dB to 37 dB and the collision frequency decreased by a factor of 1.4.

The peaks of whistler occurrence shifted to later at night and to earlier in the morning, by 2 to 3 hours, between these two periods.

Discussion: T. Laaspere (U.S.A.) doubted that the peak occurrence of whistlers was due to thunderstorm activity. Clarence replied that he had studied monthly lightning-occurrence records. Likhter stated that, during solar minimum, the solar activity was, in fact, greater. Therefore, the decreased whistler occurrence during IQSY must be strongly propagation dependent. Kimpara reported that in Japan, during both the IGY and IQSY, the whistler occurrence peaked at night and that more whistlers were recorded during the IQSY than during the IGY. Rivault commented that the results at Poitiers agreed with Kimpara's results.

C. J. Delloue: A vlf Conjugate-Points Experiment between France and South Africa. A program of recordings of natural whistlers and gyroelectric echoes generated by vlf transmitters was initiated in

1964 at Grahamstown (Rhodes University, South Africa), near the conjugate area of France.

Signals were recorded in July and August 1964 with the use of the envelope-detection method. Group time of transit as well as echo duration were found to vary in an irregular manner, even from pulse to pulse, indicating rapid fluctuations of the exit points and multipath propagation.

The dispersions and nose frequencies of natural whistlers, when recorded at the same time as the echoes, were measured. From the magnetospheric scale height thus obtained and the group time of transit of the gyroelectric echoes, the paths of the latter were deduced. Good coincidence was observed between the locations of the injection points and of the sources (i.e., the Sainte Aslise transmitter and the lightning fixes given by the British Sferics network).

Frequency-stabilized transmissions were used in 1965 and 1966 in conjunction with vlf receivers locked in phase to a stable-frequency standard in South Africa. Phase-path measurements were thus made possible with the use of a synchronous detection technique. A considerable improvement of the signal versus atmospheric-noise ratio, amounting to as much as 40 dB, was observed. The phase path was found to vary with speeds of a few kilometers per second. This technique enables the multipath echoes to be distinguished clearly by their differences in group times of transit, as well as by their differences in phase variation.

The phase-path variations measured may have been caused by the observed changes in electronic density of the conventional ionospheric layers at both ends of the paths. They are also consistent with the diurnal variation of ionization in the magnetosphere.

Simultaneous recordings were made when possible with several vlf transmitters, and on natural whistlers. The British Sferics network cooperated to record fixes of lightning flashes over Europe, and synchronization means were devised to correlate them with whistlers recorded in South Africa. Information on the relative positions of the sources and of the injection points in the magnetosphere at ionospheric levels will thus be obtained.

R. L. Smith (U.S.A.): Review of Ion Effects. Theory and whistler observations were discussed together to show the importance of ion effects, including the effects when many ion species are present in the ionospheric plasma. Various reasonances and cutoff frequencies were shown, with a short discussion of the crossover

frequency phenomena. The following whistler phenomena related to the ion effects were discussed:

1. Lower hybrid-resonance noise.
2. The lower hybrid-resonance whistler.
3. The proton whistler and helium whistler.
4. The subprotonospheric whistler.
5. The low-frequency anomalous dispersion of subprotonospheric whistlers.
6. The transverse whistler.
7. The riser whistler.
8. The check whistler.
9. An unusual effect on ray tracing, causing a trapped mode (as found by Kimura).

Discussion: T. Laaspere asked if the large- and small-scale inhomogeneities would significantly affect the agreement between theory and experiment for ion effects. D. Gurnett replied that the mode coupling that occurs for proton whistlers requires inhomogeneities.

D. A. Gurnett: Ion Cyclotron Whistlers and the Determination of Plasma Parameters. Ion cyclotron whistlers are left-hand polarized ion cyclotron waves propagating in the ionosphere and excited by lightning impulses. The theory of ion cyclotron whistlers (Gurnett, et al., 1965) shows that there should be an ion cyclotron whistler for each type of ion found in appreciable abundance (1 percent of the total ion concentration) in the ionosphere. To date, two types of ion cyclotron whistlers, the proton whistler and the helium whistler, have been observed in satellite vlf data. The theory of ion cyclotron whistlers was briefly reviewed. The work reported on here is concerned principally with the proton whistler, although the results can be applied to any type of ion cyclotron whistler.

Methods have been developed for determining ion composition and temperature in the vicinity of the satellite from ion cyclotron whistlers: (1) the crossover frequencies, which are the frequencies for which the ion cyclotron whistler and the preceding short fractional-hop whistler are coincident in time, give the fractional concentration (ion density/electron density) of each ion species; (2) the dispersion of the whistler near each ion gyrofrequency gives the absolute concentration of the corresponding ion; and (3) the cyclotron damping of ion cyclotron whistlers near each ion gyrofrequency gives the temperature of the corresponding ion.

Discussion: Laaspere again asked if these calculations are still valid in the inhomogeneous ionosphere. Gurnett stated that the WKB approximation is valid everywhere except at the crossover frequency and very close to the resonance frequencies. Johnson asked if the energy that penetrates into the ionosphere as whistlers had ever been computed. Gurnett replied that it would be estimated from the wave field strengths but that it has not yet been done.

In response to the question by Johnson about energy deposited in the magnetosphere by ion whistlers via the ion cyclotron resonance interaction, Laaspere pointed out that there is also energy deposited in the magnetosphere by the electron-cyclotron-resonance interaction. As an electron whistler propagates upward through the ionosphere and the magnetosphere, energy at frequencies above the local gyrofrequency must be absorbed. The energy deposited in the magnetosphere through this mechanism, can in principle, be calculated by taking into account such factors as thunderstorm occurrence and the transmission loss of the wave in passing through the lower ionosphere.

S. D. Shawhan (U.S.A.): New Equatorial Non-Eckersley-Law Whistlers. With satellite Injun 3, three new whistler types have been observed to occur in the equatorial region. The "hook" whistler appears as two Eckersley-type whistlers ($t = D_f{}^{-1/2}$), on a frequency-time spectrogram, that have the same lightning source and that tend to be joined at approximately 1 kHz. On a frequency-time spectrogram, the "riser" whistler appears as a rising tone starting at approximately 3.5 kHz and rising to the receiver cutoff of 7 kHz in about 0.2 sec. This whistler, therefore, has increasing time delay with increasing frequency. The frequency-time trace of a "check" whistler exhibits a check (tick)-mark shape: for a given frequency, there exist two time-delay components, the earliest in time descending in frequency from 7 kHz to about 5 kHz in frequency (receiver cutoff). These three whistlers have been observed to occur between ±30° magnetic latitude and below the Injun 3 apogee of 2,800 km.

With the use of the Haselgrove ray-tracing equations and inclusion of a centered dipole magnetic field and a diffusive-equilibrium model ionosphere, a ray-tracing program has been developed to explain these whistlers. For the hook whistler, it is found that two ray paths can exist from the lightning source to the satellite. The earliest whistler in time has increased dispersion at low frequencies, as a result of large wave-normal angles along the path. This increased dispersion causes the two traces to appear joined.

Discussion: Smith asked how the hook whistler differed from the "nu" whistler observed by Stanford on OGO I. Shawhan stated that the nu whistler data have not been published, so a quantitative comparison was not possible, but, from the sketch made by Helliwell for this meeting, it appeared that the two whistlers may actually be the same. Smith also asked why the lightning source in the hook-whistler computation was placed at 300 km. Shawhan replied that the source region was assumed to be at 300 km above the F_2 max, to simplify computations. Smith stated that the spreading of the lightning energy under the ionosphere might be important in the ray tracings. Shawhan replied that he did not believe the effect was significant. Helliwell suggested that a good test of the theory would be to identify the initial atmospheric and compare its occurrence with zero time of the computation. Gurnett asked why these three types of whistlers were not observed on the ground. Shawhan and Smith replied that the wave-normal angles for these whistlers was larger than the allowed cone of angles that can penetrate through the base of the ionosphere. These whistlers undergo total internal reflection.

A. Iwai (Japan): Nose Whistlers Observed in Japan. Nose whistlers have been observed for the first time at the latitude of Japan by the vlf receiver at Moshiri. For these whistlers, the nose frequency ranged from 45 to 65 kHz and whistler energy was observed to 100 kHz. Values of the Eckersley dispersion constant ranged from approximately 36 $sec^{1/2}$ to 86 $sec^{1/2}$ for these mid-latitude nose whistlers.

VLF Radio Waves and Micropulsations

CHAIRMAN: H. G. BOOKER

REVIEW PAPER

Fejer and Campbell (U.S.A.)

VLF Radio Waves

The survey paper by Helliwell excluded propagation phenomena, such as proton whistlers, which were discussed in the whistler session. Attention was drawn to the considerable progress made in the past three years in the theory of vlf emissions, in ground-based observations, and particularly in observations from space vehicles.

Our theoretical understanding of vlf phenomena has increased considerably, although no satisfactory detailed explanation of the frequency—time behavior of vlf emissions is yet available. It was shown conclusively that incoherent Cerenkov and cyclotron radiation by individual electrons cannot produce the observed vlf noise field and falls short by many orders of magnitude.

In spite of these difficulties, the conviction is growing that cyclotron radiation by electrons plays an important part in the generation of vlf emissions. At first, bunches of coherently radiating trapped electrons were invoked in various ways, but agreement between theory and experiment was soon questioned; in particular, the theory predicted a maximum duration of 3 to 4 sec, but longer lasting emissions were observed.

Explanations in terms of bouncing wave-packets, rather than particle bunches, were far more successful. A transverse-

resonance instability is invoked in these explanations. The instability is caused by those trapped electrons whose gyration frequency is very nearly equal to the Doppler-shifted wave frequency. The condition for instability is a sufficiently large anisotrophy in the pitch-angle distribution of trapped electrons (a depletion toward small pitch angles).

A connection between vlf emission and particle precipitation was suggested. A quantitative examination of this suggestion showed that the loss cone produced by precipitation of electrons into the ionosphere is responsible for a transverse instability which, in turn, drives more electrons into the loss cone. The flux of precipitating electrons predicted from the observed intensity of vlf emissions is, however, higher than the observed fluxes.

Ground-based observations revealed some new phenomena. Among these are vlf emissions stimulated by the dashes, but seldom by the dots, of Morse-code signals radiated from vlf transmitters.

Comparison of periodic emissions with whistlers confirms the echoing wave-packet hypothesis, in that the period of recurrence is equal to the delay of a two-hop whistler at the same frequency. Further striking proof of this hypothesis is provided by the fact that sometimes the dispersion of a triggering signal from the previous emission is observed. The echoing wave-packet hypothesis also shows promise of explaining hydromagnetic emissions. Aurora-associated hiss was found to center in the auroral zone and to extend in frequency from 4 kHz to well over 20 kHz. The correlation of hiss with absorption was positive for small absorption and negative for larger absorption, indicating at least partial control of hiss intensity by D-region absorption.

Quasiperiodic emissions or long-period pulsations having periods of the order of a minute were found to consist of bursts of recognized types of emissions. They have been attributed to modulation by hydromagnetic waves of the emission mechanism. A new class of quasiperiodic emissions was identified in which the period is an integral multiple of the period of a whistler-mode periodic emission contained in the quasiperiodic bursts.

Rocket and satellite observations show strong emissions that often are not seen on the ground. Indeed, it appears that most of the energy from lightning is absorbed in the magnetosphere. Satellite observations have also revealed an unusual band of

noise that is frequently stimulated by whistlers and is apparently related to the lower hybrid-resonance frequency.

ELF Waves and Micropulsations

In the survey of elf waves and micropulsations by Gendrin, the field was divided into three categories: earth-ionosphere cavity resonances (5 to 30 Hz); regular pulsations (Pc); and irregular pulsations (Pi).

Regular Pc1 micropulsations (also called pearls or hydromagnetic emissions) have been intensely investigated experimentally. Both their frequency and their recurrence period depend on the L-value of the line of force of their generation. The propagation of hydromagnetic emissions has been studied; the data fitted ducted horizontal propagation below the height of maximum hydromagnetic velocity, rather than downward propagation from the outer magnetosphere into the ionosphere.

The polarization of Pc1 has been measured in conjugate areas. When it is clockwise in the one hemisphere it is anticlockwise in the other, and vice versa; the same mode is thus observed at both ends of the line of force. The actual polarization frequently changes from left- to right-handed polarization, and vice versa, at one end, with corresponding simultaneous changes taking place at the other end of a line of force, as shown by conjugate observations at Sogra (U.S.S.R.) and Kerguelen Island. An antiphase relation between the times of arrival of Pc1 emissions at conjugate stations is well established; the times of arrival at the one station approximately bisect the time intervals between arrivals at the other station.

Irregular (Pi) pulsations have also been further investigated. It was found that the period of Pi2 pulsations decreases (from about 120 to 20 sec) as the solar wind velocity increases (from

about 350 to 750 km/sec).

The echoing wave-packet hypothesis, as mentioned previously, also promises to explain hydromagnetic emissions. At this time, a detailed theoretical explanation of all the observed properties of Pc1 is not yet possible, but progress has been made in the theoretical investigation of transverse instabilities caused by wave-particle gyro-interactions, and amplification coefficients have been calculated. In the case of vlf emissions, the interacting particles were electrons; in the case of hydromagnetic emissions (Pc1), they were protons. As in the case of vlf emissions,

a pitch-angle diffusion mechanism results from the instability. The theory of this diffusion has been partially worked out, and comparisons with proton fluxes observed from Explorer 12 have been made.

The special contributions to this session were similarly divided into two groups. The vlf emission topics were given first. Gurnett presented simultaneous observations, from the Injun 3 satellite, of energetic electrons and vlf noise. Hiss was observed mostly in local afternoon times, was confined to a latitude zone about 5° wide centered on the auroral zone, and occurred in the region of soft electrons with energies of 10 keV or less. Chorus was found mostly near 0900 to 1100 hours local time, well within the auroral zone, with the same spatial and time preference as the 40 keV electrons precipitated down field lines. Electron microbursts of 20 to 40 keV and about 200 m/sec duration, similar to those observed by balloon groups, were also received by Injun 3. Such bursts were always accompanying electron bursts. Belrose (Canada) presented some statistical results of the measurements of the vlf lower hybrid-resonance emissions. The polar type, at 70° to 80° latitude, had occurrence maxima at midnight and 0600 to 0800 hours and was probably aurorally related. The mid-latitude type, at 45° to 60°, was predominantly a nighttime type, occurring principally in late summer; this type was presumed to be whistler triggered. Carpenter (U.S.A.) made miscellaneous helpful comments regarding the direction of present-day vlf research endeavors. He emphasized the recent concern about the characteristics of the vlf noise-generation region within the magnetosphere. He also noted the statistical determination of vlf whistler propagation cutoff at about half the minimum gyrofrequency, apparently independent of L values or geomagnetic activity. Gendrin presented some of his laboratory's results from data taken at the conjugate observabories of Sogra (U.S.S.R.), and Kerguelen Island. Vlf chorus was not found to be correlated with either the Pc1- or Pi-type micropulsations. The vlf hiss correlated positively with the Pi and other such typically auroral disturbance phenomena. The vlf hiss always appeared similarly at the conjugate stations, but conjugate appearance of chorus occurred only when the condition $f_0F_2/_0F_Z > 30$ percent was satisfied. Owren (U.S.A.) presented some results of simultaneous observations at Vostok, Antarctica, and Quanac, Greenland, near the geomagnetic poles. The vlf emissions were found to be fewer and less intense than elsewhere in the world. Some asymmetry in the occurrence of

the low-frequency hiss at the two stations was shown. Activity increased after geomagnetic storms. Ungstrup mentioned the statistical results from studies of vlf emissions for the solar quiet years. The maximum occurrence of dawn chorus was reported at 0600 to 1200 hours, geomagnetic time, independent of latitude. Polar chorus, in contrast, reached a maximum slightly before geomagnetic noon, while vlf hiss peaked before midnight.

Two brief contributions to the discussion of the much lower frequencies were given. Nagata presented some results of new techniques for obtaining dynamic spectra of natural ulf emissions from about 0.001 to 0.07 Hz. Daily variations in frequency and amplitude for micropulsation in the Pc2 to Pc4 range were displayed. Differences in behavior for K_p variations were illustrated and said to be expected from the concurrent magnetospheric changes. Campbell presented results of observations near 1 Hz at the conjugate stations Eights, Antarctica, and Baie St. Paul, Canada, for 1964. Taking the June solstice period, when the ionosphere of Eights remained dark, and using the ratio of signal amplitudes at the conjugate sites, he obtained a measure of the changing attenuation of the Pc1 emissions. As the sun rose above the Canadian site, the relative signal level (BSP/EI) diminished to about 0.6 of its dark-period value. Effects of this small attenuation, such as a seasonal hemispherical asymmetry in the diurnal variation of mid-frequency of the emissions, were mentioned.

New Developments

CHAIRMAN: PROF. H. G. BOOKER

THE MARTIAN ATMOSPHERE AND IONOSPHERE

V. R. Eshleman (U.S.A.)

The Mariner 4 S-band occultation measurements were presented, and various analytical treatments of the data were discussed. The main uncertainty involved the interpretation of the ionospheric contribution, and models based on the earth's F_2, F_1, and E layers were considered. It appeared possible to fit the observations to any of these models, but it was noted that the E-layer model required an exceptionally high ionospheric temperature ($\simeq$ 300-400° K) and a mean mass that increased with altitude. The F_2-layer model appeared to predict that CO_2 would condense in the upper atmosphere, and the possible connection with the blue haze was noted.

THE MARTIAN MAGNETOSPHERE

F. S. Johnson (U.S.A.)

It was argued that indirect evidence favors the supposition that a small Martian magnetic field keeps the solar wind from flowing into the Martian ionosphere and atmosphere. In particular, it was noted that photodissociation of CO_2 and subsequent charge exchange between atomic-oxygen and solar-wind protons would

produce large concentrations of CO, in disagreement with observations. Moreover, if the solar wind did penetrate, a very large heat source would be present at a much higher altitude than the observed one, which is consistent with solar uv heating.

In the discussion, Ness (U.S.A.) noted that the Mariner 4 particle and field instruments had detected no signs of a transition region.

ELECTRON DENSITIES IN THE GEOMAGNETIC TAIL

V. R. Eshleman

A short summary of the radar determination of tail density (Howard et al., 1955) was presented, and some more recent unpublished measurements were discussed. More accurate ionospheric and magnetospheric corrections have been applied, and it was found that the original tail densities were too high. However, as the moon passes into the geomagnetic tail, a large change in the apparent average columnar density is still detected, with $50 < \Delta N_e < 100$.

THE GEOMAGNETIC TAIL

N. F. Ness

A summary of measurements of the distorted geomagnetic field was presented, and radio scientists were cautioned that the dipolar assumption is only valid on relatively low L-shells. It was noted, for instance, that the typical tail field of 15 to 20 γ could increase to more than 30 γ during magnetic storms, suggesting that additional polar-cap field lines were swept back into the tail region.

In the discussion, Johnson asked whether one needed to invoke Axford and Dungey's southward component of the interplanetary field to obtain the observed "neutral" sheet. Ness replied that this sheet was not really open, out to Imp orbits, and that field inflation by hot plasma or other mechanisms could explain the observed tail.

THE THERMAL PLASMA IN THE MAGNETOSPHERE

D. L. Carpenter and S. Bauer (U.S.A.)

A brief review of salient features of the plasmasphere was given. At the plasmapause, the electron density drops by a factor of 10 to 40 within a fraction of an earth radius. In the plasma trough, densities are on the order of 1 electron per cubic centimeter, and the field-line distribution of ionization appears to fall off more rapidly than within the plasmasphere.

Various sources of direct and indirect evidence of the plasmapause phenomena were briefly reviewed, including magnetospheric measurements of (1) equatorial electron density, (2) total electron content, (3) local ion density at low and middle latitudes, (4) slant columnar content to the ground at middle latitudes, (5) local electron density at ~ 2,500 km at high latitudes, (6) spatial location of triggered vlf chorus, (7) spatial occurrence of whistler activity, and (8) electron temperature near 1,000 km.

A slide showing recent measurements of the position of the plasmapause near dawn, as a function of maximum K_p in the preceding 24 hours, was presented. For a given K_p, the position lies within a well-defined belt about 1 Re wide—the center of the belt moving inward with increasing K_p, in the well-known manner.

Results of the GSFC retarding-potential analyzers on IMP's 1,2, and 3 were presented, and some evidence for a fairly rapid decrease in N was given; but the dip was not nearly as big as that obtained by analysis of whistlers and micropulsations, or the dip indicated by Taylor's OGO 1 experiment. Beyond the knee, the GSFC analyzers indicated $N_e \approx 50/cm^3$, but it was noted that some uncertainty in the effective area could modify this downward by a factor of 2 to 3.

Discussion

R. L. Smith and F. L. Scarf (U.S.A.) questioned the effective area-error estimate, since Carpenter's results would indicate a discontinuous increase in the sheath size by almost an order of magnitude as the spacecraft emerged beyond the knee. The possible effect of geomagnetic-field distortion and persistent magnetospheric inflation was raised by Bauer and Ness. Finally, Rycroft pointed out, in support of the knee measurements, that the ionospheric trough (as determined by Alouette 1) and Carpenter's

knee appeared to fall on the same L-shells, for a wide range of K_p values.

ELECTRIC FIELD MEASUREMENTS IN THE MAGNETOSPHERE

F. L. Scarf

Some early results of the Thompson-Ramo Wooldridge Systems' vlf experiment on the USAF-Aerospace Corporation spacecraft OV3-3 were presented, and it was argued that field-aligned electrostatic oscillations had been detected. The waves were measured in bandpass channels at 75 Hz, 400 Hz, 1.7 kHz, and 7.35 kHz. At the two lower frequencies, the ambient-wave amplitudes were significantly higher than those detected in the earlier 1964-45A satellite, especially at low altitudes. At 1.7 kHz and 7.35 kHz, the ambient fields were comparable to those measured two years earlier. It was also found that fringing fields from the onboard Faraday cup (modulated at 2 kHz) can generate large-amplitude electrostatic field-aligned plasma oscillations.

ROCKET MEASUREMENTS OF RADIO NOISE IN THE IONOSPHERE

T. Obayashi (Japan)

Some vlf radio-noise measurements at 0.5 - 8 kHz, made by A. Iwai and his associates, using the L-2 rocket, were reported. Two main results were discussed: (1) Large amplitude (10 mV/m) vlf electric fields were observed. The electric-field amplitudes were strongly modulated by the rocket spin, and it was concluded that the electric field of the wave is aligned along the geomagnet-field line. These waves are believed to be naturally occurring electrostatic waves in the ionosphere. (2) Sweep-frequency measurements of the antenna impedance showed that the sharpness of the upper hybrid resonance decreased with increasing altitude, suggesting plasma-wave generation near the upper hybrid-resonance frequency.

Finally, it was noted that a rocket-borne vlf-impedance probe experiment failed completely because the probe encountered very large ambient noise signals which produced saturation.

Discussion

Commenting on the papers by Scarf and Obayashi, Laaspere said that data from the Dartmouth College Whistler receiver on OGO 2, which uses a long dipole antenna, do not show electric fields of the intensity reported by Scarf.

It was conjectured that the OGO 2 results might differ from the others because of the use of a low-impedance input circuit, which might allow magnetic components rather than electric fields to drive currents through the system and govern the AGC actions.

Comment by K. Bowles (U.S.A.): Scarf has noted that input impedance for his probe is very high, and implied that this might explain why the Dartmouth probe measurements have not indicated large-amplitude electrostatic oscillations.

Bowles suggested that, if there are oscillations associated with the plasma disturbance created by the spacecraft, then the probe input impedance might well help to determine the oscillation amplitudes, frequencies, etc. It would therefore to be helpful to vary the probe input impedance as one means of distinguishing ambient-electric-field oscillations from oscillations caused by the spacecraft's disturbance of the plasma.

SATELLITE OBSERVATIONS OF IONOSPHERIC RADIO NOISE

T. R. Hartz (Canada)

Recordings made with the Alouette 2 satellite consistently show bands of radio noise at medium and high frequencies. Four distinct bands are identified, and these can be described as follows in terms of the local ionospheric conditions:

1. At frequencies greater than the electron gyrofrequency ($Y = 1$) and less than the limit for Z-mode propagation ($X = 1 + Y$), although these limits are not always firm.

2. At frequencies less than the electron gyrofrequency, and extending down to the low-frequency limit of the receiver.

3. At frequencies greater than the plasma frequency ($X = 1$) and less than the upper hybrid frequency ($X = 1 - Y^2$).

4. At frequencies greater than the limit for Z-mode propagation ($X = 1 + Y$) and less than the plasma frequency ($X - 1$).

Of these, the last three show the greatest intensities when there is evidence of local ionization irregularities, suggesting that precipitating nonthermal electrons are involved in the generation processes.

Discussion

Helliwell (U.S.A.) said that ground observations have shown that auroral hiss can be observed for frequencies up to 600 kHz. It is suggested that the noise observed below the electron gyrofrequency with Alouette 2 may be of the same origin as the auroral hiss observed on the ground.

A VLF WAVE-TRAPPING REGION

S. D. Shawhan

From consideration of the transverse-refractive index as a function of altitude for frequencies near the ion gyrofrequencies, Gurnett has shown that wave trapping may exist at altitudes near 500 km. Spectrograms from Injun 3 show distinct noise bands associated with each ion gyrofrequency at the satellite. Using vlf ray tracing, Shawhan has demonstrated this trapping of waves in the ionosphere. It is suggested that these trapped waves may cause ion gyrofrequency noise bands observed in satellites and on the ground.

PSEUDO-NOSE WHISTLERS RESULTING FROM RAY-PATH TRAPPING

R. L. Smith

Computer calculations by Kimura have shown that whistlers can become trapped in the magnetosphere, essentially following

magnetic field lines but confined to within about $\pm 30^{\circ}$ of the magnetic equator. A whistler observed by OGO 1 was presented that is believed, qualitatively, to display the ray-path behavior predicted by Kimura. These new whistlers are called pseudo-nose whistlers and appear on a frequency-time spectrogram as a sequence of nose-like whistlers which tend to occur in pairs, with the pair separation changing with latitude.

NEW RESULTS

D. T. Farley (U.S.A.)

Early theoretical calculations predicted that it should be possible to measure the ion gyrofrequency directly by means of incoherent scattering. If the radar beam is pointed nearly perpendicular to the magnetic field, the autocorrelation function of the scattered signal should have a sharp peak at the gyroperiod, $2\pi m_i/eB$. These calculations neglect the effect of ion-ion collisions, however. When these collisions are included, it is found that the gyro-resonance for oxygen ions will be very heavily damped unless the ion density is very low. For helium ions the damping will be smaller, but probably still important, while for hydrogen ions it will be negligible. Accordingly, the hydrogen resonance was searched for at Jicamarca at altitudes where hydrogen was the predominant ion. The results agreed very well with theory. A peak in the correlation functions was observed not only at the gyroperiod, but also at two and three times the gyroperiod. No helium or oxygen resonances were found.

Atmospherics II

CHAIRMAN: E. T. PIERCE (U.S.A.)

ATMOSPHERIC NOISE AND ITS INFLUENCE ON COMMUNICATIONS

F. Horner (U.K.)

Properties of noise that have been studied in recent research programs include intensities, short-term amplitude functions, and the relationship between integrated noise and the source characteristics. Comparisons have been made between intensities measured by different methods, and between measured values and those in current use for communications. Discrepancies of a few decibels exist, particularly at oceanic locations far from the main sources. Knowledge of noise in polar regions has been improved; it appears that lightning discharges may not be the predominant source of noise in the low-frequency band at high latitudes. Measurements of intensities are being extended to frequencies well below 10 kHz. Many recordings in the vlf range, primarily for ionospheric and solar research, are now being made with calibrated apparatus, and the results are available for integration into the general pattern of noise distributions.

Further measurements of amplitude probability distribution have been made, particularly in tropical regions, and there have been several theoretical analyses of idealized models of the noise to explain the form of the amplitude distributions. Reasonable agreement with experimental results has been achieved by approaches based on more than one model.

Data on the occurrence of lightning discharges obtained, for example, with lightning-flash counters, have been combined with a knowledge of their energy spectra to yield the expected noise from local storms. The values agree well with the measured values at vlf, but, in the mf range, the measured values are often much below those expected from the local storms alone. It has been suggested that typical noise recorders, because they have limited dynamic range, do not take local storms fully into account and therefore underestimate the noise power.

Estimates have been made of atmospheric noise in space, based either on the intensities measured on the ground or on the numbers and properties of individual discharges.

Reports on the application of noise data to operational interference problems are almost nonexistent, and it is not clear to what extent further, more detailed descriptions of noise are justified for communications purposes or, if justified, what form they should take.

Discussion

Vredenbregt (Netherlands) commented that, while atmospheric radio noise is usually considered a limiting factor, chiefly on the lower frequencies, it is often also true on the high frequencies, especially in the Maritime Mobile Service. More details on the amplitude-probability distribution of atmospheric noise on 4, 6, 8, 12, 16, and 22 MHz might be of use in obtaining a better understanding of reception conditions on these channels.

210 SUMMARY OF RESULTS OF ATMOSPHERIC NOISE MEASUREMENTS AT VLF AND LF IN DIFFERENT LATITUDES BY A NETWORK IN MIDDLE EUROPE, ON BOARD SHIPS, AND AT AN ARCTIC STATION.

Lauter (Germany)

During the IQSY, the mean integrated noise level was measured at Svalbard, Uppsala, Kühlungsborn, Prague, Tichany, Sofia, and aboard two ships traveling between the Baltic Sea and Zanzibar via the Mediterranean and Red Seas. The recordings were analyzed for frequency dependence and APD. The results are too numerous and diversified to summarize but should prove useful in revisions of the CCIR noise curves.

Discussion

Likhter questioned the comparison of land and sea measurements, relative to the probability distribution of resulting data. Lauter replied that their observations indicate that land-measured versus sea-measured characteristics do not differ greatly, provided the distances to the storm sources are taken into consideration.

Horner asked if the average voltage measurements had been compared with root mean square or noise-power measurements used in the CCIR reports. Lauter believed that the CCIR data is fairly accurate for Europe, but in error for East Africa.

Kimpara asked whether the measurements had been analyzed for abnormal conditions (SEA, etc.). Lauter replied that he did not wish to speak about the geophysical effects at this time, but that they are discussed in his paper "Geophysical Aspects of Low-Frequency Atmospheric-Noise Measurements" appearing in Zeitschrift für Meteorologie, Band 18, Heft 5-7-1966.

Likhter discussed variations in atmospheric radio noise with the solar cycle. He obtained minima in 1959 and 1960 and maxima in 1962 and 1963, at lower latitude observing sites, with a lag of about one year at higher latitudes. Lauter said the results were astonishing, but suggested that we should take a look at the propagation enhancements during sunspot maximum. Likhter replied that his results were for the average change for a whole day. Lauter mentioned that, during sunspot maximum, the lowering of the D region shows up as an enhancement.

Khastgir (India) discussed lateral corona from lightning channels and its influence on elf radiation. An attempt was made to show that the lateral corona currents that flow between the leader sheath and the core of the first return stroke radiate elf waves whose spectral peak amplitude of vlf waves is emitted by the return. The total energies radiated by the corona and the return were also estimated, and the difference in their magnitudes in relation to the spectral peak amplitudes was explained. The corona-current mechanism is, however, not the only source of elf energy. It was suggested that, though the long-continuing currents involving large quantities cannot be explained by the corona mechanism, they are also capable of emitting elf waves.

General Discussion of Both Sessions on Atmospherics

Pierce suggested a review of thunderstorm-day counts of Brooks and more recent observers for thunderstorm-solar-activity

correlation. Horner said he thought that the Brooks data had indicated such a correlation. Likhter mentioned that they have data from many stations over a solar cycle, and that this data should reveal a dependence.

Pierce concluded the session by announcing that Kimpara had called a meeting for 1000 hours on the following day to outline plans for Commission VIII during the next three years.

Business Meeting

CHAIRMAN: PROF. H. G. BOOKER

It was announced that the new Commission VIII has been approved by the Executive Committee and will be established as expected. The old Subcommission IVa will be dissolved.

The Executive Committee also approved the slate of officers nominated by Commission IV at the previous business meeting.

It was announced that, in the future, URSI participation in COSPAR will be on a more organized basis than in the past. The committee on space radio in URSI will be dissolved, and its functions will be assumed by the coordinating committee. Regarding URSI participation in COSPAR assemblies in the future, the Chairmen of Commissions II, III, IV, and V will be expected to attend and represent URSI.

A discussion was held on arrangements for the participation of URSI in the new Inter-Union Commission on Solar - Terrestrial Physics. There will be an URSI committee for relations with the new inter-union commission, which is chaired by H. Friedman (U.S.A.). Prof. Beynon (U.K.) is working on the organization of the URSI committee. Eventually, the Executive Committee will choose the members of this committee. Presumably, other members will be added if Friedman desires their participation. It was noted that the list of topics proposed by Friedman for the new inter-union commission does not seem to provide adequately for the interactions between particles and waves, and the Beynon committee has produced a resolution requesting a change. With minor alterations, the commission approved this resolution, as follows:

Interaction between Particles and Waves in the Magnetosphere

URSI wishes to suggest to the Inter-Union Commission on Solar - Terrestrial Physics that the following discipline be added to the Commission's list:

G. Interaction between particles and waves in the magnetosphere. This subject is not satisfactorily included in the other disciplines listed. A redefinition of one or more of disciplines A-F could possibly be arranged so as to incorporate the proposed discipline G.

Discipline G includes:

1. The interaction between the solar wind and the magnetosphere, particularly instabilities, discontinuities, and irregularities at the interface between the solar wind and the magnetosphere; and the waves into which the instabilities, discontinuities, and irregularities may be analyzed.

2. The relation between whistlers, vlf noise, and energetic particles.

3. The interaction between ambient particles, ion and electron acoustic waves, and radio waves (incoherent scatter).

These are matters of particular interest to URSI that URSI requests the Inter-Union Commission on Solar - Terrestrial Physics to recognize.

Working Group Resolution

It is presumed that the working group on synoptic whistler observations will be closely related to the committee that interfaces with the Inter-Union Commission on Solar - Terrestrial Physics. Helliwell presented a resolution prepared by the working group on this subject. There was general approval of the resolution, which follows:

Working Group on Synoptic Whistler Observations

At its business meeting, Commission IV appointed G. McK. Allcock as Chairman of this group for the ensuing three years. This group has been a subcommission under Allcock's chairmanship for the past three years. Commission IV desires that Allcock continue as Chairman under the new regime proposed in the Beynon Report. There is no objection to the Working Group on Synoptic Whistler

Observations becoming a Working Group of the proposed URSI Solar - Terrestrial Physics Commission (the replacement for the URSI-CIG Committee).

H. G. Booker
Chairman, Commission IV

Recommendations of the Subcommission on Synoptic Whistler Observations

Recommendation 1—Measurement of Noise at ELF and Lower Frequencies. It is recommended that observations of noise phenomena at elf and lower frequencies be carried out as far as possible in accordance with procedures which have been agreed upon by the subcommission and which will be published in the URSI *Bulletin.*

Recommendation 2—Recording and Data-Reduction Techniques. It is recommended that research workers studying whistlers and emissions at vlf and lower frequencies be urged to publish, or otherwise make readily available, the details of their techniques for recording and interpreting their data. Relevant technical material which is not in published form should be submitted to the World Data Centers through the chairman of the subcommission.

Recommendation 3—Amplitude Calibration of Noise Recorders. In view of increasing interest in the relative amplitudes of whistlers and emissions at different stations, workers are urged to make known the amplitude calibration of their records and to state the amplitude of the inherent noise level of their equipment as it appears on the records.

R. A. Helliwell
Acting Chairman, Subcommission

H. G. Booker
Chairman, Commission IV

It was announced that the Executive Committee had approved URSI participation in the 1968 conference on magnetospheric physics in Washington, D.C. (discussed in the notes on the previous Commission IV business session).

A formal resolution submitted for Commission IV by Chairman H. G. Booker follows:

Proposed Inter-Union Symposium on Magnetospheric Physics in 1968

At its business meeting on Wednesday, September 7, 1966, Commission IV passed the following resolution:

Commission IV believes that the recent Inter-Union Symposium on Solar - Terrestrial Physics in Belgrade should be followed by an Inter-Union Symposium on Magnetospheric Physics in 1968. Such a symposium is understood to be under consideration by the National Aeronautics and Space Administration in the United States.

The proposed topics are:

1. Inner radiation zone
2. Outer radiation zone and outer magnetosphere
3. Auroral zone and polar cap
4. Magnetospheric models
5. Geomagnetic tail
6. Magnetopause, magnetosheath, and shock front

Commission IV recommends that URSI participate in the proposed Symposium on Magnetospheric Physics in 1968 and inform the Inter-Union Commission on Solar - Terrestrial Physics of URSI's desire to participate. Commission IV further recommends that the following item be added to the list of topics:

7. Interaction between waves and particles

H. G. Booker
Chairman, Commission IV

It was announced that URSI is responding to the CCIR request regarding the radio-noise environment of spacecraft by establishing a working group. The CCIR resolution and the URSI response are as follows:

C.C.I.R.
XIth Plenary Assembly
Oslo, 1966

Doc. VI/1005-E
11 July 1966

DRAFTING COMMITTEE

The Drafting Committee, having examined Draft Questions 312(VI) submitted by Study Group VI, proposes the following text for approval by the Plenary Assembly.

Question . . . (VI)
Radio Noise Within and Above the Ionosphere*

The C.C.I.R.—CONSIDERING

(a) that radio noise is an important element in radio-communications with spacecraft;
(b) that little is known of this noise within and above the ionosphere;

DECIDES that the following questions should be studied:
1. what are the characteristics of radio noise received in a spacecraft, within or above the ionosphere;
2. what are the methods of prediction of this noise level?
Note: The following sources of noise should be considered:
1. galactic and extragalactic noise (cosmic noise);
2. solar noise;
3. planetary and interplanetary space noise;
4. ionospheric noise (noise generated within the ionosphere and magnetosphere);
5. noise of terrestrial origin (atmospheric noise and man-made noise).

*The Director, C.C.I.R., is invited to draw the attention of URSI to this Question.

Working Group on Radio-Noise Environment of Spacecraft

To answer the attached request from CCIR, the following working group has been appointed:

T. R. Hartz (Chairman)	A. Kimpara
R. Gendrin	B. O'Brien
G. Getmantser	V. I. Slysh
D. A. Gurnett	F. G. Smith
F. T. Haddock	J. L. Steinberg
R. A. Helliwell	R. G. Stone
F. Horner	K. Rawer
C. Huguenin	

The study is to cover all frequencies above 10 kHz, with special emphasis on frequencies up to 30 MHz. The study will use the review paper by Oelberman published in the IEEE Convention Review 1964 as a starting point and will incorporate the review paper written by J. L. Steinberg early in 1966.

The Chairman will receive contributions by mail from the members of the study group and will assemble them into a report, with a summary, by February 1968. Copies will be sent to the Chairmen of Commissions III, IV, and V and to the Secretary-General of URSI by 1 March 1968. The Secretary-General will forward the report to CCIR in March 1968 unless objections are made by the Commission Chairmen.

H. G. Booker
Chairman, Commission IV
(Acting also on behalf of the
Chairmen of Commissions III & V)

12 September 1966

218 Likhter suggested that too little has been done in past deliberations regarding standardization of synoptic whistler observations. He expressed dismay that this subject had not been mentioned in the documents of the working group. Helliwell replied that there is general concern on this account but that it is still too early for standards to be established.

It was placed on record that both the URSI subcommission on Synoptic Whistler Observations and the appropriate CCIR committees should urge their members to work toward the point where observing standards may be technically possible.

Effects of Nuclear Explosions on Radio-Propagation Phenomena

CHAIRMAN: PROF. H. G. BOOKER

Nuclear explosions create new ionization in the ionosphere, change the spatial distribution of existing ionospheric ionization, and generate radio signals.

The energy equivalent released by an explosion with a kiloton yield is usually taken as 4.2×10^{19} erg (4.2×10^{12} J). The nuclear radiations from an explosion are relatively independent of its altitude and consist of approximately the following percentages of the yield: prompt γ rays, 0.1 percent; neutrons, 1 percent; delayed x rays, 2 percent; and delayed β rays, 2 percent. For high-altitude explosions, thermal x rays account for 50 to 70 percent of the yield, and a few percent is released as light waves and in blast and shock waves. For low-altitude explosions, a negligible percentage of the yield escapes as x rays, while about 35 percent is released in light waves and 50 percent in blast and shock waves.

New ionization is produced in the upper atmosphere as a result of a nuclear explosion. For high-altitude (hundreds of kilometers) explosions, very large regions are affected. Regions within line of sight of the explosion are ionized by γ rays, neutrons, β electrons, and debris. Regions beyond the line of sight may be ionized by β electrons and protons, which proceed along magnetic field lines after decay of a neutron that has traveled radially outward to great distances. Likewise, β electrons from un-ionized debris can result in ionization beyond the line of sight. Ionization from γ rays and neutrons occurs at heights as low as 25 to 30 km, while that caused by x rays and β electrons occurs at heights down to 50 or 60 km. Impact of debris with the upper atmosphere results in ionization

at heights above about 100 km. Beta electrons become trapped by the earth's magnetic field and migrate around the world, unless their pitch-angle distribution causes them to interact with the atmosphere (particularly probable in the North Atlantic magnetic anomaly).

For explosions at low altitudes (tens of kilometers), all radiation is contained initially by the atmosphere; the air is heated and fully ionized in a limited volume, and a fireball is formed. The fireball and heated air rise rapidly and, at heights of 20 to 30 km, γ rays and neutrons escape upward and begin to ionize sufficient areas to affect radio waves.

Shock waves are produced by explosions at low altitudes and in the ionosphere. At great distances, these waves become acoustic or gravity waves. Radio observations have shown the effect of these waves on the distribution of electrons in the ionosphere. The theory of propagation of acoustic and gravity waves and their interaction with the ionosphere is complicated because of the coupling of the motions of the neutral and the charged constituents, and is further complicated at high altitudes by interaction with the magnetic field.

The radio signals generated by a nuclear explosion consist primarily of two types: (1) a large-amplitude short-duration electromagnetic pulse generated at the time of the explosion; and (2) small-amplitude long-duration "synchrotron" noise from high-energy β electrons trapped in the earth's magnetic field.

This review includes selected references from the several hundred published papers that discuss the effects of nuclear explosions on the ionosphere.

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COMMISSION V

RADIO ASTRONOMY

CHAIRMAN: W. N. CHRISTIANSEN (Australia)

First Business Meeting

CHAIRMAN: W. N. CHRISTIANSEN

Professor Christiansen opened the meeting by describing the program for the sessions of Commission V. Speakers had been arranged in advance for all sessions. It was agreed that the first speaker at each session should be session organizer and chairman for that session. Although meetings of other commissions were referred to in the published program for Commission V, there were to be no joint sessions of Commission V with other commissions. Professor Christiansen outlined the way in which the present program came to be arranged. This led the meeting to a discussion of President Koga's description of the work of URSI in his address at the opening session of the General Assembly. He said that the purpose of the General Assembly was not to present original scientific and technical papers. The objects of the Assembly were stated under seven headings by President Koga (see the President's speech), and Professor Christiansen suggested that Commission V might like to consider the President's statements and how they affected the Commission's future program. Professor Hagen (U.S.A.) and Professor Swenson (U.S.A.) spoke on this subject and, with others of the commission, emphasized the value of the past URSI assemblies to radio astronomy, when the Commission sessions had, in fact, been the equivalent of scientific meetings. At the end of the discussion, Professor Hagen agreed to form a small group to draft a resolution from the commission on this subject.

Professor Christiansen outlined the new methods by which commission chairmen and vice-chairmen would be selected. It would be necessary for the commission to advise him of possible candidates. Both appointments would be made by the URSI Executive

Committee. It was agreed that a list of possible names would be supplied by Commission V to Professor Christiansen. (Note: see the meeting notes of September 6, which follows.) The Executive Committee would then nominate a chairman to follow Professor Christiansen and a vice-chairman who would become chairman 3 years later. It was agreed that the election of Commission V secretaries should be deferred until the new chairman and vice-chairman are known so that at least one secretary can be chosen who lives fairly close to the new chairman.

Reporters for all sessions were selected. In all cases, the English-speaking reporters chosen were identical with those already charged by the U.S. National Committee with preparing a report on the Commission V sessions. Professor Laffineur (France) agreed to act as chief French-language reporter.

Professor Christiansen had been asked to prepare a written report describing the last 3 years' progress in radio astronomy. After some discussion on the motion of Dr. J. P. Wild (Australia), seconded by Dr. A. Maxwell (U.S.A.), it was unanimously agreed that no such report would be written.

The task of editing the Commission V proceedings and of sending the edited result to the Secretary-General was accepted by J. W. Findlay (U.S.A.). Only papers that were in his hands by October 1, 1966, would be included.

The printed program was somewhat in error, so that the Second Business Meeting was arranged to take place on September 12. It was also agreed that a short business meeting could be held before any regular Commission V session (reports on two such short meetings follow).

SHORT BUSINESS MEETINGS HELD SEPTEMBER 6 AND SEPTEMBER 8

On September 6, the commission voted on names to be suggested to Professor Christiansen for the new chairman and vice-chairman. Professor Christiansen accepted the advice of the meeting and, subsequently, the Executive Committee announced the following appointments:

Chairman	E. J. Blum (France)
Vice-Chairman	C. A. Muller (Netherlands)

On September 8, another short business meeting was held to consider the draft of a resolution prepared by Professor Hagen. The following draft resolution was read:

Considering:

1. That URSI objectives are to "develop, on an international basis, scientific studies relating to radio."
2. That in radio astronomy the most effective means for establishing an international exchange on a timely basis is at a General Assembly.
3. That the development of studies is heavily influenced by prior and current activities.

It is resolved that:

1. Sessions of Commission V of URSI at a General Assembly shall consist of:
   (a) Sessions in which scientific papers reporting original work in radio (including radar) astronomy are presented.
   (b) Sessions in which techniques and equipment peculiar to or advancing the art of radio astronomy are reported.
   (c) Sessions in which review papers prepared by authorities in the field are presented, and in which adequate time for discussion is allowed.
   (d) Business sessions in which the administrative affairs of the commission are discussed.

Sir Bernard Lovell (U.K.) strongly supported the resolution. From his experience as a former Commission V chairman, he welcomed the value of past URSI meetings to radio astronomy and hoped that the restatement of the work of the commission would be approved. After a vote, the resolution was unanimously approved by the commission.

Filled-Aperture Radio Telescopes

CHAIRMAN: F. G. SMITH (U.K.)

INTRODUCTORY PAPER

F. G. Smith

In 1890, the year in which Edison devised the first radio telescope, Michelson made the first successful optical stellar interferometer. He did this by covering up most of the aperture of an 11-in. telescope, leaving only two slits whose distance apart could be varied. Thirty years later, he treated the 100-in. reflector on Mount Wilson to a similar indignity, covering with canvas all but two 7-in. holes near the ends of the aperture; this time, he obtained the first resolution of a stellar diameter, the work that was later completed by the addition of the periscopic arrangement of four mirrors familiar in the textbooks.

How was it that Michelson was able to improve the performance of a telescope by covering up all but 1 percent of its aperture? For many of us now this is not a difficult question, since we have seen radio telescopes develop into the two families of the single dishes and the interferometers, and we have a very clearly worked out theory relating the configuration of a telescope aperture with the kind of information that we can obtain with it.

The parallel with radio astronomical investigations of angular diameter is evident. The development of radio telescopes has, however, followed a different course from that of optical telescopes. We do indeed have the radio version of the Michelson interferometer, measuring fringe visibilities at spacings of over one million wavelengths; the age of the 100-in. and 200-in. telescopes, representing

the most powerful means of penetrating deep into the universe, is matched more by the aperture-synthesis radio telescope than by the single steerable paraboloid. This is a contrast which may lead us to think of the "big dish" approach as old-fashioned.

I propose to concentrate on this contrast, and I shall try to show that radio telescopes should follow both lines—the Fourier and the Newtonian approaches of synthesis and large steerable reflectors—and, further, that advance in instrumental techniques is entirely possible on both these lines.

The advance on the usual optical techniques represented by aperture synthesis is possible in radio astronomy because it is possible to preserve phase coherence in signals collected at widely separated points—points further apart, in fact, than the maximum feasible dimensions of a single steerable aperature. The difficulty of achieving this coherence at optical wavelength is illustrated by the difficulty of constructing a Michelson steller interferometer with a base line longer than 10 m.

In the design of radio telescopes, we are facing a problem akin to the electronic engineering process of matching. If we know what kind of information we want, we can build apparatus to obtain it in the most efficient way. For example, if we were looking for a feature of the sky that contained primarily high-order Fourier components, we would find it convenient to explore the complex correlation at large separations on the ground, rejecting the unwanted low-order components that are known to contain large signals from other sources. Again, if we are looking for a narrow spectral feature, we use a narrow-frequency bandwidth or, perhaps, an interferometric filter of high order.

Before considering specific observational tasks, let me explore a paradox in this question of information rate. The synthesis of an aperture by a simple interferometer provides a survey of an area of sky in which the sensitivity is $2/\sqrt{n}$ of the sensitivity obtained from the full aperture, where n is the number of separate positions or arrangements required in the interferometer. Following this kind of analysis, we know that the 1-mile telescope has the sensitivity of a single aperture over 1,000 ft in diameter, achieved by the use of three paraboloids only 60 ft in diameter, whose total collecting area equals that of a single aperture only 100 ft in diameter. The synthesis technique has given a spectacular improvement, in sensitivity as well as in resolution, over the performance of any conceivable pencil-beam telescope.

Here is an example of match and mismatch. The synthesis telescope is matched to the problem of mapping in detail the area of sky inside the primary beam of the individual dishes; its sensitivity is achieved by integration over a period of some days or weeks. A single dish with a larger collecting area actually rejects radiation from outside its primary beam. If the single dish is used for surveying the sky for point sources, it should not be used with a single pencil beam, but with a multiple beam.

Other problems for single apertures are at the short wavelengths, where the optical approach is most appropriate, and at long wavelengths, where the symmetry or simplicity of the single dish is necessary. For simplicity, the single dish is suited to H-line studies, and, for symmetry, it is essential for polarization studies of the galactic background.

To match the wide range of problems, it seems worthwhile to have fully steerable dishes, not only specifically for the short wavelengths—say, for optimum performance at $\lambda = 1$ cm—but also for considerably larger ones designed to work with maximum gain at about $\lambda = 10$ cm, and full efficiency at 21 cm.

Size and Surface Accuracy

The theory by Ruze has been found to work well in practice, and we can set a meaningful limit of $\lambda/20$ rms for the surface tolerance, with 1 dB loss of gain. Taking $\lambda = 10$ cm for example, we have a tolerance rms error (ϵ) of 0.5 cm, or peak errors not exceeding ± 1.5 cm over most of the surface. For a diameter D = 100 m, the ratio D/ϵ would be 2×10^4, which is achieved in somewhat smaller reflectors. Values of D/ϵ for a selection of accurate reflectors are given in the table, which is based on figures given by Hutchinson at the recent IEEE conference in London. Comparable figures are given for aperture synthesis and a long base-line interferometer.

Location	Diameter	D/ϵ	
University of Texas	5 m	6×10^4	
Serpukhov	22 m	5×10^4	
Goonhilly II	26 m	3×10^4	
M.I.T. Haystack	36 m	3×10^4	
CSIRO Parkes	64 m	2×10^4	
Cambridge Synthesis 8 m	500 m	5×10^4	(limited by ionosphere)
Cambridge Synthesis 21 cm	2,000 m	4×10^4	
Jodrell-Malvern	140 km	10^6	(assuming rms error of about 20 cm)

Control and Guidance

The application of the digital computer to the Jodrell Bank Mark II telescopes by Davies has shown what can be achieved by a fully adaptable servo-control system. The Class II servo which he has used contains terms that can be adjusted by the operator to remove known errors, such as refraction and encoder misalignments, and which can also be made to adapt automatically to changing conditions. The computer still has spare time to control experimental apparatus as, for example, by inserting the appropriate fringe speed and delay into an interferometer. This telescope, with its associated radio-astronomy receiver, can now run unattended for periods up to 24 hours. We need not worry about this aspect of control, but the problems of accurate angular indication and of dynamic behavior are accentuated as beamwidths come down below 10 minutes of arc.

Feed Systems

The wider use of low-noise amplifiers has redirected attention to the development of suitable feeds. It is only recently that a full analysis has been available of the aperture efficiency and spillover noise, even for simple feeds with polar diagrams of the form $\cos^m \theta$ in paraboloids of various values of f/D ratio. Now we learn that multimoded horn feeds can provide greatly improved performance, with efficiencies over 80 percent and a very small spillover.

A Spectrum of Telescopes

Studies of the future development of radio astronomy made in various countries have concluded that two types of telescopes should be built—synthesis and pencil-beam. Let us not be misled by oversimplification. There is in fact a gradation of types, from the single pencil beam, through simple interferometers and gratings, both at regular spacings and using Arsac arrays, to synthesis, using any number of fixed elements with one or more mobile elements. There is no universal radio telescope waiting to be built; there is scope for great ingenuity in combinations of gratings and synthesis to cover as many problems as possible, and there is still a wide range of problems for the fast, simple, single paraboloid. How to

divide one's resources, if one must divide them, depends on detailed studies of the cost of paraboloids, both the largest possible and the medium sizes used in gratings and synthesis. There are no simple rules relating cost to diameter, but there is one clear fact; namely, the large steerable telescope, the gratings, the synthesis telescopes, and the radio telescopes launched in satellites are all becoming very expensive, and we must be sure that, when we build a new one, we build a really good one.

RADIO TELESCOPES WITH NONCIRCULAR APERTURES

A. Boischot (France)

It is evident that a fully steerable single reflector, such as a paraboloid, is the best antenna for most of the radio astronomical observations. It gives the largest surface for a given size, and the best resolving power in all directions for a given surface, and it can be pointed in any direction of the sky at any moment.

But there is a limitation to the size of the paraboloids that can be built. This limitation is due to technical (and, hence, financial) difficulties which are encountered in building very high, nonfixed structures. The difficulty of achieving a given accuracy on the surface and on the pointing increases very rapidly with the height of the structure, especially as the mechanical stresses change with change of position. That is why radio astronomers designed other types of antennas to obtain either very high sensitivity or high resolving power for a lower cost.

The three main characteristics of a radio telescope are (1) its sensitivity, i.e., its total area; (2) its resolving power, in α and ζ, given by its sizes in E-W and N-S direction; and (3) its ability to be pointed in a given direction of the sky—its sky coverage.

The different systems that I shall speak of sacrifice at least one of these characteristics to increase the others.

The difficulties in building high structures will lead to noncircular and asymmetrical apertures in general much longer than they are high. The three types of radio telescopes I have to study are: (1) the cylindrical paraboloids; (2) the Pulkovo type; and (3) the Kraus type.

Cylindrical Paraboloids

The best example of this type is the Vermilion River radio telescope of the University of Illinois. We must also include the arms of Mills crosses, which are very often cylindrical paraboloids, but they will be studied in another session. The very interesting project of the Indian radio astronomers is also an antenna of this shape but with different characteristics, as it will have a nonfixed surface.

The Illinois telescope consists of a cylindrical parabolic surface fixed on the ground, and its construction leads to some problems very similar to that of the fixed spherical reflector of the Arecibo type, to which it might be compared. This type of antenna gives a very large surface for relatively low cost, but the principal limitations come from the complexity of the feed system. To have a good resolving power in right ascension, the focal length must be large and, also, the height of the feed line must be great. This feed line must have a large number of elements, each with its phasing system. Even so, the sky coverage is limited by the difficulty of obtaining good lobes, without secondaries, in a large range of directions. For instance, the Illinois telescope is limited to observation between $\zeta = +10^\circ$ and $+70^\circ$. This limitation is also due to the geometry of the system, which does not allow observations at low elevations.

Pulkovo Telescope

This type is made of a section of paraboloid or revolution with a focus fixed on the ground. It is a transit instrument, and the change in elevation of the beam is obtained by modifying the surface of the paraboloid itself. This necessitates a reflector built with many small plane elements which can be adjusted separately; moreover, to adjust each element, you must move it with three different motions. The Russian astronomers have undertaken a very large antenna project of the Pulkovo type, working down to 10 cm, with a circle of 10 km radius and panels as high at 100 m. Some of the limitations of such an instrument are the same as those we shall meet on the Kraus-type antenna.

The Kraus Telescope

In 1955, John Kraus proposed and built a new type of radio telescope at Ohio State University. We built another one in Nançay, with slight

modifications. The focalization is obtained by a completely fixed vertical reflector, which is a section of a paraboloid or a sphere, with its focus close to the ground. The rays coming from the source are directed into this reflector by a second one with a plane surface in front of it. The elevation of the beam is then given by the inclination of the plane reflector, and we may change the direction of observation by changing this inclination.

There are two main differences between the Ohio State University and Nançay telescopes:

1. The first uses a reflecting ground plane between the two reflectors, with the axis of rotation of the plane on the ground. This has several advantages over the Nançay telescope, which employs a nonreflecting ground plane, but which does not allow movement of the focal antenna to track a source.
2. The possibility of following a source is one of the main characteristics of the Nançay telescope. This is done in a limited range of $0 \pm 7.5°$ around the meridian and allows us to make 1-hr integration on each source.

To conclude, I would like to emphasize a very important point relative to the noncircular apertures in general. It is evident that, in some observations, it is easier to use a circular beam given by a circular aperture.

The final limitation of a large radio telescope is always the confusion. One must observe, on the average, only one source in 10 or 20 lobes. It must be noted that this limit given by the confusion is less stringent if we compare observations made with instruments of different characteristics, mainly with a main lobe of different shape and a different distribution of secondary lobes. Thus, it will always be very useful to build noncircular as well as circular-aperture radio telescopes.

LARGE PARABOLIC RADIO ASTRONOMY ANTENNAS

John W. Findlay

Introduction

The large parabolic-reflector antenna has proved itself to be a basic instrument for research in radio astronomy. Such reflectors

have been built either in fully steerable or partially steerable form with diameters up to 300 ft. There seem to be no fundamental difficulties in achieving increases of linear size or perhaps a factor of 2.

Typical Antenna Design and Performance

We will summarize antenna practice under various headings. In doing so, some generalization is necessary, but the results quoted are typical of several of the better antennas which have been built.

(1) Structural Shape

Reflector Shape. A circular reflector aperture has been preferred by almost all designers; it also seems to be preferable from all the radio performance viewpoints.

Focal Point Location. The instruments designed solely for radio astronomy have generally been prime-focus telescopes with a focal length/diameter (f/D) ratio between 0.25 and 0.5. There has been a preference for f/D values around 0.4; this choice seems to give an approximate optimization of many conflicting requirements.

Reflector Figure. Good measurements have now been made of the relationship between aperture efficiency of a parabolic dish and its surface irregularities. These measurements show good agreement with antenna-tolerance theory. An antenna which is to perform at a wavelength of λ_{min} should have an rms value of $\lambda_{min}/40$ for the deviations of its surface from a true best-fit paraboloid.

(2) Radio Characteristics

Primary Feed Illumination. The types of feed illumination used vary somewhat with the operating frequency. At the higher frequencies, where horn feeds can be used, the primary feed pattern is usually adjusted so that the illumination toward the edge of the dish is 10 to 15 dB below that toward the center. Such a feed taper results in aperture efficiences of about 60 to 65 percent. Some dishes have been used with feeds of special design in attempts to reduce spillover and approach a more uniform illumination over the dish. Tests show that the spillover is reduced, but none of

these feeds has so far resulted in increasing aperture efficiencies much above the 65-percent level. At longer wavelengths, single dipoles or groups of dipoles are used, but the control of primary feed illumination is less precise.

Half-Power Beamwidth (HPBW). Most feeds result in a far-field pattern for the dish, with a HPBW of about 135 λ/D (HPBW in minutes of arc, λ in cm, and D in feet).

Side-Lobe Performance. Use of the sort of feed taper described above normally keeps the side lobes adjacent to the main beam at a level of 22 to 25 dB below the main lobe. When lower spillover primary feeds are used, the more uniform illumination results in higher first side lobes, about 18 dB below the main lobe.

The far-out side-lobe level, with well-designed dishes, is usually best described by saying that no side lobe approaches the gain of an isotropic antenna. The measurement of these side lobes is difficult.

Aperture and Beam Efficiency. At wavelengths longer than λ_{min}, good parabolic dishes with tapered feeds give values of aperture efficiency of 60 to 65 percent and of beam efficiency of about 75 percent.

Antenna Temperature. Antenna temperatures, with the beam directed to the zenith of 25° K to 35° K, have been measured for good parabolic prime-focus dishes. Some carefully fed Cassegrain dishes have shown antenna temperatures as low as 15° K.

Polarization Performance. This is usually described by giving the instrumental polarization when the antenna is directed to a small-diameter unpolarized radio source. A linearly polarized feed is rotated at the focal point, and the percentage variation measured in the received signal is the instrumental polarization. It can be as small as 1 percent.

Radial- and Axial-Feed Movements. Movements of the feed away from the true focus along the axis of the parabola result in defocusing of the telescope. It is found that the antenna gain drops, the beam broadens, and side lobes rise as the feed position moves from the true focus. However, for a dish of f/D = 0.42, an axial defocusing of $\lambda/4$ reduces the gain by only 5 percent.

Parabolic dishes are quite sensitive to radial movements of the feed away from the focus. It is well known that a radial movement of the feed changes the beam direction and also introduces coma. The gain drops appreciably as the feed is moved off axis; again, at f/D = 0.42, a beam movement of 0.20 HPBW results in a 3-percent gain loss. Coma lobes near the main lobe develop quite quickly as the beam moves off axis. For f/D = 0.42, a beam movement of 3.5 HPBW resulted in the growth of coma lobes only 10 dB below the main lobe.

(3) Mechanical Characteristics

Wind and Weather. Telescopes are usually built to survive wind speeds of 120 mph; some in special situations will survive greater speeds. These extreme conditions can only be met with the reflector in a stowed and locked position. Only the 120-ft Haystack antenna of the large instruments so far built, has used a radome.

Drive and Position Indicator Accuracies. The over-all drive precision usually demanded is that, in winds up to 25 mph, the telescope should track with rms angular errors less than 0.20 of the HPBW at λ_{min}.

The Future of Large Parabolic Antennas

Design Techniques

The developments over the last 10 years in the design of large structures have been much influenced by the problems created by the need for large antennas. The most significant change has been the introduction, test, and validation of computer analysis of the stresses and deflections of structures. Many designers have developed such programs or have access to them. Of these, the Stair and Fran programs are perhaps the best known. During the design of Haystack, for example, both methods were used and, as a consequence of a careful measurement program, the validity of the results was established. Such results are of great importance for the future of antenna design in that gravity deflections and, to a lesser extent, wind and thermal effects can be reliably predicted.

There is no absolute limit to the size of an antenna other than that set by the stress - density relations for structural materials. For steel, this suggests a limit in size of about 600 m in diameter, a figure of not much interest in practice, since the cost of such a telescope would be extremely high.

SPHERICAL REFLECTIONS IN RADIO TELESCOPES: A CRITICAL STUDY

William E. Gordon (U.S.A.)

Spherical reflectors provide large collecting areas (on the order of 10^4 m^2) with limited sky coverage in antennas for radio astronomy. The collecting areas are large because the reflector is fixed in position; the sky coverage is achieved by moving the feed but not the reflector.

The near side lobes have not been suppressed sufficiently for most mapping purposes, although current research on feeds for spherical reflectors is likely to solve this problem.

Antenna theory and spherical optics provide the specifications for the feed, the reflecting surface, and the motion of the beam through the sky. These were outlined. The four large spherical reflectors currently in use were described, and their principal antenna parameters were listed.

Discussion

Lovell: I should like to suggest that we should perhaps design instruments that do not have low distortion and high efficiency. For the same cost, we could then build a much larger instrument. Although it would be inefficient at the shorter wavelengths, it may well have a higher gain than a smaller, rigid instrument.

Moffet (U.S.A.): I agree with Prof. Lovell that useful work may be done with an antenna at wavelengths where its gain has started to fall off, especially when this drop-off is due more to permanent surface irregularities than to deformations under gravitational or aerodynamic forces. Certainly, a lot of good astronomy has come from antennas working at geometrical efficiencies of about 0.35, but this ought not to be taken too far. If an antenna sags so much that its efficiency drops to around 0.15, then the corrections for gain

changes and pointing errors will be such strong functions of pointing angle (and perhaps of wind conditions) that no one will trust any observations that come from it.

THEORY OF TENSOR FOURIER SYNTHESIS AND ITS APPLICATION TO RADIO ASTRONOMY

H. C. Ko (U.S.A.)

A unified theory of radio-astronomical measurements is presented under the framework of the theory of partial coherence. In particular, the theory of tensor Fourier synthesis is developed, by which both the polarization distribution and the brightness distribution of a radio source can be synthesized from the four polarization coherence functions. These four coherence functions are:

$$\Gamma_{ks}(u, v) = \left\langle E_k\left(\frac{x}{\lambda} + u, \frac{y}{\lambda} + v, t\right) E_s^*\left(\frac{x}{\lambda}, \frac{y}{\lambda}, t\right)\right\rangle$$

for k, s = x, y. The polarization distribution and brightness distribution are simultaneously obtained by Fourier-inverting of the polarization coherence functions.

An interferometric polarimeter which simultaneously measures the four polarization coherence functions is described, and its application to radio astronomy is discussed. The polarimeter consists of two separated antennas, each having a cross-dipole feed. The outputs from each feed are correlated with those from the other feed, yielding four outputs.

Discussion

Bracewell (U.S.A.): Dr. Ko's presentation should be regarded as a clear and pleasing discussion of polarimetry and not as an alternative to observational procedures in use. According to the particulars of a given source, it may be preferable to rotate antennas rather than use fixed orientations, but Ko's formulation is adaptable to such alternatives.

Maltby (Norway): Could you tell me the difference (in particular, concerning the time involved in making the observations) between the method you are suggesting and the method already used at the California Institute of Technology by Radhakrishnan, Morris, and Seielstad?

Ko: My analysis is based on the coherence matrix rather than the Stokes parameters. The method I proposed makes it possible to measure all the required parameters simultaneously instead of sequentially. Furthermore, it does not contain redundant data and therefore it is the most economical way, from the theoretical point of view.

Moffet: In connection with the design of a new multi-element interferometer for the Owens Valley Radio Observatory, we have thought quite a bit about the optimum way to measure the brightness distribution of the polarized and unpolarized emission from discrete sources. Take the simplest case of a single antenna equipped with a pair of orthogonally polarized feeds: It is, in practice, not sufficient to make measurements with only a single-feed orientation. At least two sets of measurements are required, with the feeds rotated by 45° between sets. (The angle need not be exactly 45°, but it must be precisely known.) The reason is that, with only one set of measurements, the polarization can at times depend on the difference between two very nearly equal quantities, both of which suffer from uncertainties of measurements. This difficulty exists whenever the degree of polarization is small, as it is for many sources. A similar argument holds for the interferometer. All the various representations of polarized emission are simply related to one another. Whether one chooses to use the Stokes parameter or some other form is more or less a matter of taste. The Stokes representation does have the advantage that the unpolarized, the linearly polarized, and the circularly polarized parts of the emission are represented by independent numbers, and this is often quite convenient.

Ko: For a strongly polarized source, it is necessary to measure with only one feed orientation, as I described in the slide. For a very weakly polarized source, it is better to measure more than once to confirm the result. In such a case, it is better to measure the second one with different feed orientation, such as 45° from the first one.

As to the comparison between the Stokes parameters and the coherency matrix, I think that the coherency matrix is a much better formulation than the Stokes parameters, for aperture-synthesis or interferometric work or both. In the interferometric polarimeter I have discussed, each of the four outputs measures directly each of the four elements of the coherency matrix. The interpretation is straightforward, simple, and clear. Such a formulation cannot be made using the Stokes parameters, since it is theoretically

impossible to design an antenna that can measure only one of the Stokes parameters. Any antenna always measures two or more parameters at the same time, and one must sort them out.

In classical optics, where only the intensity (but not the phase) can be measured, the Stokes parameters are as convenient as the coherency matrix. However, in radio astronomy, where one always measures the fringe amplitude and phase, the coherency matrix is a more natural and straightforward representation.

Unfilled-Aperture Radio Telescopes

CHAIRMAN: MARTIN RYLE (U.K.)

APERTURE SYNTHESIS

Martin Ryle

The principle of aperture synthesis was reviewed, and there was a discussion of the relative sensitivites of aperture-synthesis and filled-aperture instruments. Several examples of both one-dimensional and two-dimensional synthesis instruments were discussed, in terms of sensitivity and observing-time requirements.

The Cambridge 1-mile telescope was discussed in some detail and recent results of observations shown. The Cambridge instrument is a full two-dimensional synthesis telescope employing three 60-ft diameter paraboloids (two fixed and one moveable) with full sky coverage. The new telescope was designed primarily:

1. To obtain the positions of sources with sufficient accuracy (~1 second of arc) for unambiguous identification to be made with fainter optical objects.

2. To obtain detailed maps of the structure of individual sources. Although observations with simple interferometers to sample the Fourier transform of the source distribution have allowed the construction of simple model distribution, which can well account for many of the sources, a considerable number are too complex. A detailed investigation, at different wavelengths and polarizations, of the structure of both radio galaxies and supernova remnants seems likely to be essential for understanding the physical mechanisms occuring within them.

3. To extend observations to fainter sources in order to further investigate the cosomological problem; such observations require an increase in both resolution and sensitivity, compared with those of the 4C survey at 178 MHz.

The method of two-dimensional synthesis, employing the rotation of the earth to alter the projection of an E-W axis on the sky, has proved to be a very economical method of achieving high resolution and high sensitivity; maps of individual sources with a resolution of 23 seconds of arc at 1,407 MHz and 80 seconds of arc at 408 MHz have revealed many interesting features.

The application of the method to the detection of weak sources has provided maps with a combined noise and confusion level at 408 MHz of $\sim 2 \times 10^{-29}$ wm^{-2} $(c/sec)^{-1}$.

Observations made with a 1,200-ft dish capable of operating efficiently at a frequency of 2,000 MHz and used with a system noise of 50° would provide a comparable resolution and signal-to-noise ratio if used to survey the same area of sky in the same time.

Discussion

Heeschen (U.S.A.): Aperture synthesis is being done at the National Radio Astronomy Observatory (NRAO), using two 85-ft diameter antennas at 11-cm wavelength. The maximum baseline is 2,700 m, giving a resolution of 8 seconds of arc. Observations of Cygnus A made by Clark, Hogg, Tyler, and Wade, and analyzed by Wade, were illustrated. With a resolution of 8 seconds of arc, the two well-known components of Cygnus A break up into a number of intense small-diameter sources irregularly distributed within each component. The most intense of the small sources are of a factor of about 20 more intense than the broad distributions of the two components. It is also evident that Cygnus A is not yet fully resolved with a resolution of 8 seconds of arc.

It is clear than Cygnus A has a very complex structure and that even greater resolutions will be required to study the structure and polarization of this source and other sources.

Swenson: Is not the interferometer much less susceptible to radio interference than are single-aperture radio telescopes?

Ryle: Yes; however, the interference we experienced was very strong and in the protected radio astronomy band. The interfering signal (from aircraft) was ultimately changed to a different frequency.

Swenson: Would your baseline constants be better determined by radio astronomy techniques (observing known position sources) than by ground survey?

Ryle: Yes. We do it both ways, of course; however, there were discrepancies between the values obtained by the two techniques, and we wished to resolve these. New ground survey results now approach those determined by radio techniques.

Christiansen: We need to standardize on a definition of sensitivity. You have mentioned one; Hogbom, another. There are at least two useful definitions.

Ryle: The definition I used is the correct one for survey work.

EARTH-ROTATION SYNTHESIS USING FIXED ANTENNAS

J. Hogbom (Netherlands)

All the necessary E-W spacings on the ground can be present simultaneously when using arrays of smaller units, instead of a few large antennas. The telescope is then a one-dimensional synthesis instrument and all the u,v plane, out to a given maximum, can be covered in a single 12-hour period. One advantage of such fixed systems is that the total observing time can be better adjusted to the sensitivity requirements.

Two sensitivities for synthesis arrays are defined. One, the "source sensitivity," is applicable when the area of the sky to be synthesized is less than the element primary beam. The second, the "survey sensitivity," applies when the synthesis area is larger than the element primary-beam area. Comparisons were made between arrays containing a relatively large number of small fixed antennas and those consisting of a few large moveable elements. The surveying sensitivities for the small-element arrays are better, in proportion to the square root of the primary-beam areas, provided the total collecting area has been made equal in both cases.

A discussion of the problems arising from grating lobes was given, and some small-element array configurations were shown.

OPTIMUM SPACINGS FOR RADIO TELESCOPES WITH UNFILLED APERTURES

R. N. Bracewell

Let four antennas be arranged along a straight line in a pattern described by the sequence of numbers $\{1\ 1\ 0\ 0\ 1\ 0\ 1\}$. The 1's give the antenna locations and the 0's denote unoccupied locations. The autocorrelation sequence $\{1\ 1\ 0\ 0\ 1\ 0\ 1\}^{*2} = \{1\ 1\ 1\ 1\ 1\ 1\ 4\ 1\ 1\ 1\ 1\ 1\ 1\}$ represents the spectral sensitivity of the array.

When the number of antennas exceeds four, there are no arrangements giving uniform spectral sensitivity; either there are (1) some redundant spacings or (2) some missing ones.

A favorable systematic arrangement was discussed. Given an odd number n of antennas (which is slightly advantageous), place $(n + 1)/2$ together, then an equal number of unoccupied sites, then another antenna; then put $(n - 1)/2$ blanks plus one antenna $(n - 3)/2$ times. The maximum spacing reached will be $S = (n^2 + 2n + 1)/4$. If n is even, $S = n^2/4 + n/2$, $n > 2$. The spacing that would be reached if uniform sensitivity could be achieved is $B = (n^2 - n)/2$. The fraction S/B was tabulated for various unswitched arrangements.

When switching is allowed, uniform sensitivity is always possible. When n is even, there should be n/2 antennas in each group, and the maximum spacing S is given by $S = n^2/4$. However, either of the adjacent possibilities containing $n/2 - 1$ in one group and $n/2 + 1$ in the other has a maximum spacing $n^2/4 - 1$, which is only one unit less. When n is odd, $S = n^2/4 - 1/4$ is the maximum spacing, and it is achieved with $(n + 1)/2$ in one group and $(n - 1)/2$ in the other, in either of the two possible ways. The adjacent possibilities have maximum spacings only two units less.

It appears that the unswitched arrangement permits better resolution. An example illustrating equal resolutions is as follows:

6 antennas switched: $\breve{1}\ \breve{1}\ \breve{1}\ \breve{1}\ \breve{0}\ \breve{0}\ \breve{1}\ \breve{0}\ \breve{0}\ 1$
5 antennas unswitched: 1 1 1 0 0 0 1 0 0 1

Several arrangements were shown for both the switched and unswitched cases.

An array of five antennas arranged in this way is under development at Stanford, with the following parameters:

Unit spacing	L = 22.9 m
Reflector diameter	4L/5 = 18.3

Over-all length	9L = 205.7
Wavelength	2.8 cm
Beamwidth on meridian	17 sec of arc
Fringe spacing	4.2 min of arc

Discussion

Moffet: As Professor Bracewell observed, the problem of obtaining the optimum combination of n elements to obtain the greatest numbers of multiples of a unit spacing is of interest to number theorists. A paper by Leach gives the optimum combinations for $n \leq 12$.

J. G. Davies (U.K.): In a study that Dr. Thomson and I carried out, we found arrangements of antennas with all spacings from two to the maximum, and with minimum redundancy. The unit spacing was omitted because of the practical difficulty of one antenna shadowing its neighbor. These components must be obtained in another way. Eleven elements can provide all spacings, up to about 45 units.

Christiansen: There is an important advantage in making these array configurations quasi-symmetrical, in that the phasing errors are more easily eliminated.

THE CORRELATOR ARRAY

G. W. Swenson, Jr. (U.S.A.)

The correlator array consists of a number of antennas that are connected in pairs by multipliers. Each pair measures one Fourier component of the sky brightness distribution. If a sufficient number of base lines are present, the brightness distribution can be reconstructed by taking the Fourier transform of the data. Use of supersynthesis (hour-angle tracking) greatly increases the number of Fourier components available from a given set of physical base lines.

The available Fourier components can be determined by projecting the aperture-planes distribution of antenna elements onto the celestial sphere in the vicinity of the source to be mapped. The autocorrelation function of this projection is the set of Fourier components available and is termed the "transfer function" of the array. The National Radio Astronomy Observatory has prepared computer programs for evaluating the transfer functions of correlator arrays,

including the effects of hour-angle tracking. The parameters include the number and arrangement of the antenna elements in the aperture plane, the declination of the source, the latitude of the telescope, and the hour-angle interval. Many configurations have been studied, including the T, the circle, the cross, and the Y. The goal of the study is to find an array that yields 3-sec resolution in a 5-min field of view, while minimizing the number of elements and the hour-angle interval.

The Y-shaped array, with approximately 40 elements, yields acceptable results under the widest range of operating conditions and permits relatively easy expansion to better angular resolution.

Discussion

Hogbom: In the figure depicting the side-lobe structure, is this inside the primary field of view?

Swenson: Yes, the side lobes outside being worse, of course. However, the array will still be sensitivity-limited rather than confusion-limited.

Hagen: What are the levels of these side lobes?

Swenson: Of the order of -20 dB or better.

F. G. Smith: Are all pairs of antennas correlated?

Swenson: Yes, except for a few that are always redundant or always outside the resolution limit.

PARTIALLY FILLED ARRAYS

W. N. Christiansen

Some advantages and applications for partially filled arrays, such as the Molongola Cross, were discussed. This type of array is particularly advantageous for solar and galactic work. The capability of producing simultaneous multiple beams lends itself to the observation of variable sources. The "cross" arrangement was stressed in favor of the "T", in order to avoid phasing problems in the nonsymmetrical arrangement.

Discussion

Erickson (U.S.A.): With regard to Dr. Christiansen's comments, I should like to mention that I have been operating an instrument at

decameter wavelengths which is essentially a "T", not a "cross." At such wavelengths, no trouble is experienced in maintaining the correct phase relationships at the center, and the fact that the antenna gives both a sine and a cosine response is of considerable advantage. Measuring both these responses allows one to measure both the strength of a source and its position in the beam simultaneously, without the necessity of scans at adjacent declinations. This greatly improves the accuracy of declination measurements with such an instrument because ionospheric scintillations in the amplitude of a source do not affect the determination of its position.

LOW-FREQUENCY PARTIALLY FILLED ARRAYS

C. H. Costain (Canada)

The 22.5 MHz and 10.02 MHz dipole arrays of the Dominion Astrophysical Observatory were discussed. Details on these instruments can be found in the Transactions of the Royal Society of Canada, p. 419 (June 1965). Some results of observations were shown and discussed.

CIRCULAR ARRAYS

J. P. Wild

The difference between image-synthesis and aperture-synthesis telescopes was discussed. An example of an image-synthesis telescope—the circular array of the CSIRO Solar Observatory at Culgoora—was discussed in some detail. The annular aperture consists of 96 paraboloid reflectors (each 13 m in diameter) arranged in a ring 3 km in diameter. The wavelength of operation is 3.75 m. Further details are available in Proceedings of the Royal Society (London), Series A, 286, 499 (1965).

Discussion

Thomson (U.K.): What are the advantages of the circle over the "Y" or "T" or "cross?"

Wild: The cross has twice the largest dimension. Most importantly, the circle has the best symmetry, in that the phasing error side lobes are distributed uniformly. Thus, the phase tolerances are not as severe. Next, we wish to use optical processing for the data. This is simpler to do for the ring.

Westerhout (U.S.A.): What is the status of the circular array?

Wild: 80 to 90 percent of the electronics is complete. It will take 6 to 8 months to complete the installation.

Ko: Do you make polarization measurements?

Wild: Yes; specifically, we will obtain a 60 × 50-point picture in two circular polarizations each second.

Radio Techniques

CHAIRMAN: E. J. BLUM

IMAGE FORMING AND STABILITY IN RADIO TELESCOPES

E. J. Blum

Image and Information

The concept of forming an image was treated first. The meaning of the word "image" is not necessarily precise, either in optics or in radio astronomy. In many images, there is much superfluous information, but the images of radio astronomy are tedious to form and generally contain only necessary information. This is often "filtered" information; for example, the 4C survey was made with the use of high-bass filters for the spatial frequencies. Although complete images are very desirable in radio astronomy, much has been done with highly filtered data, as with the use of scintillation observations to measure the sizes of small radio sources.

Atmospheric Effects

The effects of irregularities in the atmosphere are well known to optical astronomers. In radio, the National Bureau of Standards has studied effects near the ground. At NRAO, in Green Bank, both these effects and those of the whole depth of the atmosphere have been studied. It seems that wavelengths from 5 cm to 50 cm are best for high-resolution work and that the atmospheric resolution limit may well be less than a very few seconds of arc.

Phase Stability

Several good solutions for getting good stability have now been found, including phase-lock systems. Stabilities of a few angular degrees over a few kilometers seem possible.

New and Projected Multi-Output Antennas

We use the term "multi-output" rather than "multiple-beam" to cover a variety of antennas. The new Mills and Bologna crosses, the Wild circle, Ryle's instrument, and the projected NRAO instrument are examples. The techniques of these instruments will all be discussed, but questions remain, for some more than for others. Can the very high resolutions in complete images be obtained? The natural limits may be near. Has the optimum coverage of spatial frequencies been achieved? Is this desirable for all problems in radio astronomy?

Discussion

Baars (Neth.): Correlation between meteorological conditions and phase stability has been found at Green Bank.

STABILITY IN ELECTRONIC EQUIPMENT

R. Aitchinson (Australia)

In multibeam systems, a large amount of electronics is required. In view of the cost of antenna steelwork, it is logical to put strict tolerance on the electronic equipment so that it does not degrade the performance. As a specific example, results for the 1.6-km Mills cross near Canberra are used.

Owing to its size, such an antenna is split up into a large number of modules. Conversion to an i.f. reduces the effects of cable loss, so each module comprising mixer, local oscillator feed, and i.f. amplifier is mounted in the open on the antenna. Each module must behave in the same way in phase and amplitude to avoid degrading antenna performance. The limits are set by considering side-lobe levels and pointing accuracy.

The signals are processed and combined in an observation building, usually with a milder climate, to form one or a number

of beams. In the Mills cross, 11 beams are formed. The same uniformity of phase and amplitude applies to all units that handle signals before correlation. In addition, high stability and dynamic range are important factors. The limits are determined by many variables, including the number of significant levels to be measured, the required linearity, and the immunity required from signals in the fan beams, but not in the pencil beam.

I will refer only to items in which special problems arise.

Antenna Mounted Units

Radio-frequency amplifiers have been considered in this and in other commissions. Commonly, with hundreds of units involved, the input stage is a mixer and a following i.f. amplifier. In the choice of i.f. and bandwidth, obvious costs (cable and delay units) tend to keep the values low. However, for phase and amplitude stability and for linearity, no such obvious limits exist, and phase and amplitude stability are required to be as high as possible. As an indication of values, the figures for the Mills cross are: differential phase ±5°/MHz, amplitude ±0.5 dB/MHz (extreme values between any two units over a temperature range of -5° C to 25° C). Values apply to the central 2.5-MHz bandwidth of a 4.2-MHz band centered at 11.05 MHz. There is little published material on phase tolerance and methods of achieving phase uniformity.

At the same time, the i.f. is required to have low noise and high selectivity. Noise figure in itself is not a problem. With the use of inexpensive transistors, with a little selection, values indicated in the following table are obtained (for bandwidths greater than 50 percent, values are higher):

	Frequency (MHz)			
	10	30	200	400
Noise figure (dB)	0.09	1.2	≈2.5	≈4.5
Phase shift (degrees)	< 10	< 15	≈30	≈60

For phase and amplitude stability in the transistor, there are no problems at normal i.f. However, the phase shifts indicated in the table (values for typical transistors) become appreciable at frequencies higher than 100 MHz, and uniformity and stability of phase could be a problem. However, the situation is quite different for

band-pass circuits. The phase slope increases with the order and is $\approx 1\text{-}1/2^{\circ}$ per 1 percent bandwidth for a 4th-order system, and ≈ 2.2 per 1 percent bandwidth for a 6th-order system. High phase slope inevitably means higher errors in phase, with exact values depending on manufacturing methods and temperature changes.

Amplifiers in Observatory Building

The problems here are different, as the temperature range is far lower, and, although uniformity of phase and amplitude must still be maintained, this is not a problem. A second conversion is a useful feature, as the first L.O. frequency can be phase locked to hold the L.O. line electrical length constant. It can also be used to set phase (by varying second L.O. phase), gain, calibrate, and adjust for i.f. amplitude-frequency slope. Immunity to phase changes with L.O. level and gain change is desirable, and these can be achieved fairly readily at the level of ±0.5 dB. However, the major problems occur after the signals are combined. Detectors, demodulators, and correlators must handle, simultaneously, large signals, both correlated and uncorrelated. In an interferometer, this arises from sources in the fan beams but not in the pencil beams. In the synchronous demodulator, the same problems arise and, in addition, dc stability is important. A somewhate higher range is desirable to allow operation with large offset for total-power recording and to ensure zen stability for long periods of observation.

Discussion

Blum: Have you noticed any changes in the phase stability of the amplifiers caused by aging of components?

Aitchinson: Only one unit in about 200 shows aging problems.

Burns (France): If the data are put into digital form as early as possible, one is no longer constrained to realizable functions, and the phase amplitude relations are released. Would this be applicable to your system?

Aitchinson: I believe the problems will be similar. I see no real difference between the methods.

DIGITAL DATA PROCESSING

S. Weinreb (U.S.A.)

Three factors are likely to greatly increase the use of on-line computing facilities in radio astronomy: (1) the large cost reduction in digital logic elements, (2) the increasing cost of producing state-of-the-art observing instruments, and (3) the increasing complexity of the observations. These factors combine to justify the use of quite sophisticated digital equipment to obtain as efficient a use as possible of large radio telescopes.

In this paper, the configuration and application of on-line computers at NRAO was described. Four small computers are on order or are being installed for use at the NRAO 36-ft, 140-ft, and 300-ft telescopes and at the three-element 85-ft interferometer.

The computers on the NRAO telescopes are used for the following tasks:

1. Coordinate conversion on alt-azimuth telescopes.
2. Antenna control; that is, scanning, pointing corrections, and on-and-off-type observations.
3. Data integration and recording: the computer will allow flexibility in recording format, immediate testing of data, and magnetic tape recording speed.
4. Autocorrelation receiver transforms: in the digital autocorrelation receiver, the Fourier inversion will be performed on line.
5. Interferometer delay line control: the computer will control the insertion of delay in the arms of the interferometer and also provide an on-line calculation of fringe visibility and phase.
6. Real-time position and flux analysis: the computers will provide a real-time measurement of the flux, position, and width of radio sources. The input data will be estimated coordinates of a radio source. The computer then executes scans near this position; it finds the peak and it then computes and prints out the output data.
7. Adaptive receivers: the computer will control the noise source and front-end switch so that three states are provided: (1) calibration on, switch in antenna position; (2) calibration off, switch in antenna position; and (3) switch in reference position. A change from one state to another would be made every few milliseconds. By processing the receiver outputs, the three unknowns of antenna temperature, receiver gain, and receiver noise temperature can be independently determined. This provides a receiver with great

flexibility and several advantages, among them being the advantage that the computer can adjust the portion of time spent at each of the input states so that the fluctuation in the antenna-temperature measurement is a minimum, for a given receiver stability.

8. System monitor: the computer will monitor a number of parameters in the system and automatically make adjustments or signal an alarm when they exceed given tolerances.

Discussion

Hewish (U.K.): What is meant by ordinary calculations in Fourier transformations?

Weinreb: The standard method, using n^2 multiplications.

Findlay: How do you take care of the problem of nonlinearity in the detector in an adaptive receiver?

Weinreb: The departure from square law must be corrected in the computer. However, the detection is square law over a 10-to-1 range, and the corrections are small.

Ponsonby (U.K.): There is no synchronous detector in Weinreb's scheme. Another way of doing this is to use a voltage-to-frequency converter and to switch its output between the two counters. The difference between the counters then gives the output.

OBSERVING TECHNIQUES WITH ON-LINE COMPUTER CONTROL

R. G. Davies

The Jodrell Bank Mark II radio telescope has been used as a total-power instrument at wavelengths of 21, 11, and 6 cm, both in studying the spectra of radio sources and in the study of about 100 planetary nebulae. Three types of receivers have been used—switched, correlator, and 1-bit digital correlator. In each case, two feeds are arranged, horizontally displaced about the focus, thus providing two beams separated by about 0.6° at 21 cm and 0.2° at 6 cm. The output of the receiver is a measure of the difference in aerial temperatures between the two beams. Each beam is directed at the source, in turn; thus, the source temperature is established relative to the mean of two regions, one on each side of it.

The computer performs the following functions:

1. Coordinate conversion, allowance for refraction, beam deflection, etc.
2. The servo loop is closed by the computer, output voltages to the servo amplifiers being adjusted four times per record.
3. When the actual position of the radio telescope lies within 0.01° of the source position, the receiver output is sampled four times per record.
4. When sufficient data are obtained, usually after 32 samples, or 8 records, the telescope is moved so that the second beam is directed at the source.
5. The mean value and rms deviation of the samples are computed, and any samples more than 3 standard deviations from the mean are rejected.
6. Stages (3), (4), and (5) are repeated until the required information has been acquired, after perhaps 100 samples of the difference between the signal in each of the two bands have been obtained.
7. The telescope is moved to the next source in the observing list, and the mean, plus its standard deviation, is computed, once again rejecting points of large deviation.
8. A discharge-to-noise source is switched on to provide a calibration of the receiver.

The rms following error of the telescope at any steady speed, from sidereal rate to 25°/min, is about 0.003°, in winds of 25 mph.

All encoder and structural deflections are derived from the bright radio sources and corrected in the computer. The mean pointing error remaining after this is about 0.005°.

This method of observation results in a very fast observing system, and it is an example of a technique developed to take full advantage of the possibilities of real-time computation available when the telescope control and data processing take place in the same computer.

REDUCTION OF TROPOSPHERIC NOISE FLUCTUATIONS AT CENTIMETER WAVELENGTHS WITH THE USE OF A DUAL-BEAM OBSERVING METHOD

J. W. M Baars (U.S.A.)

A special technique for radio-astronomical observations at centimeter wavelengths that largely eliminates the influence of radiation

fluctuations from the troposphere on the sensitivity of the radio telescope has been developed. Successful tests have been performed at wavelengths of 9.5 mm and of 2 cm and 6 cm on the NRAO 140-ft telescope. The radiometer is switched between two feed horns, both located close to the focal point of the paraboloid, and the difference in power is recorded. Two similar beams are projected on the sky, separated by some small angle. Close to the antenna (in the Fresnel region) the cylindrical beams partially overlap. By keeping the source in one of the beams only, its flux density is measured while simultaneously canceling the atmospheric noise, because such noise enters the two overlapping beams.

Discussion

Smith: In the 6-cm observations, is it clear that the fluctuations were caused by the sky? Did you use switched receivers in both cases?

Baars: Yes, the same receiver mode was used.

AN IMAGE-FORMING RADIO TELESCOPE WITH REAL-TIME DISPLAY

J. Ponsonby and M. Komesaroff

It is shown that, in a conventional television display, there is an ordered and direct correspondence between the Fourier components of the time-periodic video waveform and the two-dimensional spatial Fourier components of the intensity distribution which form the picture. This result may be used as the basis of an analog computer for performing two-dimensional Fourier transforms.

The "aperture-synthesis" technique is a two-dimensional Fourier transform performed on the measurements obtained by a series of radio-interferometer observations, each measuring one spatial frequency component of the sky-brightness distribution. If all the necessary interferometers are realized simultaneously, signals proportional to the cosine and sine of spatial-frequency components may be made available simultaneously and could be used as input to the analog computer for producing a real-time display. The number of elementary "beams," or picture points, is approximately equal to twice the number of elementary interferometers.

RADIO TELESCOPES EMPLOYING REAL-TIME SYNTHESIS

R. M. Chisolm (Canada)

The paper described an analog device that forms a one-dimensional radio picture of a strip of the sky lying along the observer's median. The image is formed instantaneously and is presented on the screen of an oscilloscope. In this system, the various harmonics generated by a harmonic generator are controlled by correlators operating between the elements of an antenna. When the signals from the harmonic generator are added together and displayed on an oscilloscope, a real-time picture of this radio sky is produced.

Discussion

Wild: Can this method be applied to aperture synthesis by summing photographically?

Chisholm: I am somewhat afraid of two-dimensional systems, but it probably could be done. We plan to store data and process later.

Wild: You must be able to do aperture synthesis with a one-dimensional system.

Ponsonby: In my scheme, you don't need n^2 demodulators. I see the possibility of 1,000 beams and 50 kHz bandwidth with one coherent integrator.

POLARIZATION MEASUREMENTS

C. A. Muller

Measurements of the polarization characteristics of the radiation of galactic and extragalactic objects and of the galactic background form one of the important advances in radio astronomy of the last decade.

This talk on polarization measurements will be limited to linear polarization, with an emphasis on the measurements of the linear polarization of the galactic background radiation. The problems of circular polarization will not be discussed.

The various methods used for polarization measurements are nearly all improved versions of the methods used in the first experiments, and I will summarize the various methods used for a single dish:

1. The first method is that with a simple rotating dipole as used by the NRL group for their polarization measurements on the stronger sources, which resulted in the polarization of the radiation from the Crab Nebula.
2. The second method uses orthogonal dipoles in the focus with the dipoles connected to the two inputs of a switch, a method being used successfully by the Cambridge group in its backbround polarization measurements.
3. Another method is the use of a correlating receiver connected to the orthogonal dipoles first used, I think, by Thomson in his first experiments and, later, by our group with the Dwingeloo telescope.
4. A further modification is possible by combining the difference and correlation systems.

The paper concluded with some comments on the technical problems encountered in the correlator methods used by the Dwingeloo group.

Discussion

Tyler (U.S.A.): We have measured the cross-polarized side lobes of the NRAO 85-ft telescopes, using a TRG feed, and found them to be 26 dB below the main beam.

Baars: The 1 to 2 percent polarized side lobes reported by Muller are somewhat higher than expected for the f/D of that telescope. Improvements can be achieved by using a Cassegrain system.

Thomson: Which is better, the Cassegrain or the Gregorian system? Some people feel that the Gregorian gives lower spillover and cross-polarization.

More Synthesis and Techniques

CHAIRMAN: M. R. KUNDU (INDIA)

F. G. Smith reviewed the status of frequency allocations for the radio astronomy service [most of the relevant data is contained in a paper by R. C. Smith—Rose in Nature, 203, 7 (1964)]. Smith suggested that a strong effort be made to protect the deuterium line and adjacent frequencies; specifically, the band from 322 to 329 MHz. He suggested that it might be a good bargain to give up the 409 to 410 MHz band, if this were the cost of obtaining the 322 to 329 MHz band. Those present appeared to agree with these suggestions.

B. J. Robinson (Australia) asked that every possible effort be made to protect the OH lines, including the lines at 1,612 and 1,720 MHz and other spectral lines, including those as yet undiscovered. He also discussed the need for advance information on spectral lines, saying that it is common to wait until a line is observed, then plead for an allocation when the plea is too late. We see lack of foresight in the clearance of the bands from 2,690 to 2,700 MHz and 4,990 to 5,000 MHz. These miss some hydrogen lines, yet several of these lie within 10-Mc bands above 2,700 and 5,000 MHz. However, the spectrum is now allocated, and the chances of changing it are immeasurably small.

C. Costain (Canada) expressed the opinion, based on his studies, that the decameter guard bands are useless.

F. D. Drake (U.S.A.) expressed a hope that the 606 to 614 MHz band would receive continued protection because it is optimum, in many respects, for interferometry.

Hughes (Canada) proposed that a band be set aside for a cw-transmitting satellite to be used to calibrate long-base-line inter-

ferometers. Ryle opposed this suggestion on the grounds that a satellite, at a frequency close enough to the operating frequency to be useful, would interfere with actual observations.

ABSOLUTE CALIBRATION OF SIGNAL INTENSITIES

W. J. Medd (Canada)

The stronger discrete sources have been measured at many frequencies up to 15.5 GHz, with accuracy varying from 2 to 6 percent probable error. There are no serious discrepancies between the various results. However, a closer examination reveals that, in various detailed aspects of the subject, there are a number of inconsistencies and deficiencies remaining. There are frequency ranges over which very few accurate source measurements have been made. The extension of our knowledge to frequencies above 15 GHz, although difficult, is very important. Over much of the microwave regions, it is within the state of the art to gain an accuracy of 2 or 3 percent probable error for the stronger discrete sources; yet this has seldom been achieved in practice.

The various problems involved in absolute calibration were reviewed. In particular, the problem of determining accurately the antenna gain, the antenna temperature, and atmospheric attenuation were discussed in detail. The problems involved in relative flux measurements and measurements of sky brightness were also discussed.

ABSOLUTE CALIBRATION OF THE FLUX DENSITY OF SOLAR RADIO EMISSION

H. Tanaka (Japan) and T. Kakinuma (Japan)

Though the internal accuracy has been improved for most of the long series of solar radio-flux observations, absolute values do not fall on smooth frequency spectra. Referring to the spectra based on the recent calibration at Nagoya, the values deviate from these curves by about 15 to 20 percent. It was pointed out that a consistent daily calibration is fundamental to absolute calibration,

and some technical problems were discussed. Finally, cooperative work on the absolute calibration was proposed, considering the importance of consistency in worldwide observations.

SOLAR ABSOLUTE MEASUREMENTS

A. Kruger (Germany)

The present international situation of solar absolute measurements at centimeter and decimeter waves was considered. The observations of the Heinrich Hertz Institute, Berlin-Adlershof, were compared with those of other stations. Finally, the consequences of absolute measurements for the knowledge of the spectra of the quiet sun and the S-component were briefly discussed.

During the last cycle of solar activity, a number of observatories were concerned with daily observations of solar-flux density in the microwave region. Efforts have been made in the area of absolute calibration of the radio telescopes used for this purpose, but comparisons of the measurements at different stations show some discrepancies in the determination of the absolute flux level at wavelengths greater than 8 cm.

Discussion

Maltshanov (U.S.S.R.): At Leningrad University, we measured the solar emission using the emission of the moon for calibration. In all cases, at $\lambda = 3.2$ cm, we found good agreement with the data published by Nagoya University and the Heinrich Hertz Institute. With the moon, on longer wavelengths the absolute calibration gave different results.

In the future, the comparison of solar-flux data from different stations will be easier if the ratio of solar flux to lunar flux is also published. This assumes that the variation of lunar flux is well known and does not change.

A. Maxwell (U.S.A.) suggested a reactivation of the Commission V subcommittee for solar calibrations, in view of the discrepancies that seem to be present in this area.

H. C. Ko (U.S.A.) mentioned that new theoretical procedures at Ohio State University have led to a better ability to calculate the gain of standard gain hours than previously. It is published in

PGAP. The discussion then turned to long-base-line interferometers, with a description by Smith of the work of the Jodrell Bank group led by H. Palmer. Slee (U.K.) described a 38 MHz base line interferometer at Jodrell Bank.

Laffineur described the long-base-line interferometer at the observatory of Haute-Provence.

A discussion of the limitations on phase stability in such interferometers followed. Smith stated that phase deviations occurred throughout the Jodrell Bank system, particularly in the mercury delay lines.

REVIEW PAPER

W. C. Tyler (U.S.A.)

The observations performed with the two-element interferometer at Green Bank and the improvements of this system to provide a three-element, 2,700-m base line (λ = 11 cm), high phase-stability instrument were described. A transportable 42-ft antenna, which will operate with the three-element interferometer for base lines up to 600,000 λ, was also described.

Discussion

Smith asked what type of delay line would be used in the 600,000 λ interferometer. Tyler replied that a stepped quartz delay line would be used.

261 RADIO INTERFEROMETER PHASE FLUCTUATIONS AND METEOROLOGICAL INFLUENCES

J. W. M. Baars

An attempt has been made to correlate discontinuities and random fluctuations in the phase of the interferometer fringe output with meteorological variations. The interferometer works at a wavelength of 11 cm with base lines between 10,000 and 25,000 λ.

Use was made of local weather recordings and United States weather maps. A clear correlation was found between the rms scatter in the phase and the general type of weather; the smallest phase scatter (about 0.1 rad) was found during calm and dry weather with clear skies, while the scatter is about five times larger in rainy and cloudy weather. The stronger the variations in humidity during the observation and the higher the humidity in the atmosphere, the larger is the phase scatter. Frontal activity is important; very low phase scatter occurs in the absence of fronts and with a high barometric pressure. A local stationary front, however, coincides with the highest scatter values.

Discussion

Ryle asked what type of cable system was used in the interferometer. Baars replied that buried cable was used, except for the length of line going up the antenna.

REVIEW PAPER

J. L. Yen (Canada) and R. M. Chisholm

They described the instrumentation of an interferometer operating at 448 MHz on a base line of $5 \times 10^6\ \lambda$. The interferometer utilizes independent local oscillators (rubidium frequency standards) at each station with data recording on the same type of high-speed analog magnetic tape recorders that are used for television recording.

Discussion

Drake reported that a similar independent local oscillator interferometer was being constructed for use between the 140-ft telescope at Green Bank and the 1,000-ft telescope at Arecibo. An operating frequency of 608 MHz will be used. A major difference in instrumentation is that one-bit digital recording and correlation will be used.

TWO-DIMENSIONAL APERTURE SYNTHESIS IN LUNAR RADAR ASTRONOMY

J. H. Thomson and J. E. B. Ponsonby

It was shown that, when a distant object, such as the moon or a planet, is observed by a cw radar employing a single antenna, components of the two-dimensional Fourier transform of the target's radar-brightness distribution may be obtained by computing the autocorrelation function of the complex amplitude of the returned signals. When the motion of the radar, relative to the target, is suitable, sufficient components may be measured to allow the two-dimensional radar-brightness distribution to be recovered.

This process has been carried out in the case of the moon. Observations have been made with a radar, operating at a wavelength of 73 cm, transmitting circularly polarized signals and receiving the orthogonal polarization. Reduction of the data has enabled an unambiguous two-dimensional map of the lunar radar-brightness distribution to be constructed with an angular resolution of 3 minutes of arc.

Solar Radio Spectroscopy: Interplanetary Plasma

CHAIRMAN: J. P. WILD

RADIO SPECTROGRAPHS FOR OBSERVATION OF THE SUN

J. P. Wild

Broad-Band Spectrographs

In early spectrographs, the main technical problems were the making of sensitive swept-frequency receivers and, to a lesser extent, wideband antennas to match the receivers. In recent years, great advances have been made in both antenna and receiver techniques. Nowadays, the limiting factor in spectrograph design is probably the accuracy, presentation, and economic handling of the voluminous data which a spectrograph yields. The broad features of the sun's spectral activity are now known and increasing attention must be focused on the more subtle phenomena, which impose a greater demand on the quality of the recorded data.

Let us consider how a modern broadband spectrograph might be designed, to cover as much of the radio astronomy spectrum as possible. We start with the following definite specification; the numerical values given can be varied at will without affecting the general philosophy:

Frequency range: 8 to 2000 MHz

Frequency law: logarithmic

Frequency resolution: the log frequency range to be divided into 1,000 equal resolution cells (corresponding to $\delta f/f = 0.0055$)

Scan repetition rate: 4/sec

Intensity range: 0 dB (quiet sun level, where feasible) to 40 dB
Intensity resolution: 0.5 dB

Receivers. Receivers, especially at meter wavelengths, have been transformed in recent years with the arrival of transistors of very large bandwidth—gain products (which allow the construction of simple low-noise amplifiers with bandwidths of several hundred megacycles per second) and with the introduction and development of voltage-variable capacitors. Advances at the higher frequencies have been made possible by the availability of traveling-wave tubes, backward-wave oscillators, and various solid-state devices, such as parametric amplifiers, tunnel diodes, etc. The result is that now 10:1 frequency ranges can be covered by voltage-tuned swept-frequency receivers up to 2 or 3 GHz.

Meter-wavelength receiving systems can at present be made with noise temperatures of about 10^3 °K, and decimeter-wave length systems, 2 to 3×10^3 °K. In both cases, use is made of up-conversion to a high intermediate frequency so that the heterodyne oscillator need only be tuned over a narrow relative range of frequencies. In the meter-wavelength receiving system, use is made of a broadband amplifier ahead of the sweeping circuit. Caution is needed in the use of broadband preamplifiers, since all signals and harmonics received in the wide range of frequencies appear simultaneously in the mixer, and the dangers of cross-modulation must be watched.

Antenna Problem. The antenna problem has been eased by the introduction of log-periodic antennas. Whether these antennas are used as individual elements or broadside arrays or to feed parabolic mirrors, they can comfortably cover frequency ranges of 10:1 with remarkably constant gain and good impedance characteristics. The more recent variety, in which dipole elements of different lengths are mounted on a single boom, is particularly simple and is also suited for use in crossed pairs for measurements of polarization.

When used for ordinary spectral observations of the sun, paraboloids cannot be used at gains greater than about 10^4, if the beam is not to become too narrow to cover the solar disk with reasonable uniformity, nor can they be used at gains less than about 50 if gain variations due to standing waves between feed and mirror are to be avoided. It is possible that the lower limit could be removed by the use of offset feeds.

The logical choice for frequencies lower than about 100 MHz appears to be the log-periodic antenna, either single-element or broadside array. At very low frequencies (~10 MHz), the quiet-sun threshold would require a large number of elements, each of very great size. For this reason, weak phenomena at these frequencies remain unexplored at the present time.

In planning a new spectrograph for Sydney, we have divided the proposed frequency range, 5 to 2,000 MHz, logarithmically into five sections, each 3:1 in span. The upper two sections (222 to 2,000 MHz) are to be covered by a 6-m dish feeding a 9:1 decimeter-wavelength receiver; the others will be covered by a 13-m dish, a twin log-periodic antenna, and a single log-periodic antenna, respectively, each feeding 3:1 up-converter meter-wavelength receivers. The sensitivity requirement of detecting the quiet sun at the low-frequency end has been abandoned, at least for the time being, owing to the very large antenna structures required.

Display Units. The way in which the spectral information is displayed and recorded greatly influences its subsequent usefulness. A-scan displays require tedious reduction and synthesis to produce dynamic spectra and are best suited to special investigations where accurate spectral profiles are needed. Analog recording with magnetic tape has been successfully used at Toyokawa as a means of economizing in film. The most widely used type, however, is intensity modulation of cathode-ray tubes, which gives qualitative dynamic spectra directly. Its main disadvantage is its requirement for use of microphotometry for quantitative information on intensities. With multirange spectrographs, the need also arises to combine the data of several receivers, preferably on the same photographic film.

Uniformity of Record. Unless special provisions are made, the output of a radio spectrograph will show unwanted variations across the scan which are mainly of instrumental origin. These variations are of two kinds: (1) variations in background noise—mainly receiver noise at the higher frequencies and galactic noise at the lower frequencies; and (2) variations in gain with frequency, due to the antenna, antenna - receiver matching conditions, and the receiver. In the past, these variations have usually been ignored, although it is desirable and feasible to eliminate both kinds of variations.

Control System. A control system is required to regulate all time-dependent operations and waveforms of the equipment as a whole.

The Photographic Record. The final record may be considered as a matrix of rectangular cells whose side length in the f-direction is d/n, where d is the useful width of the film. To make the resolution properties of the record equal in both coordinates, we make the cells square, and so move the film at a speed of (d/n) Rd/n, where R is the scan repetition rate.

It can also be shown that, with careful choice of film and proper handling, 80 distinguishable logarithmic steps, each of 0.5 dB, can be recorded.

The Detector. Photographic film is basically a logarithmic recorder, while the brightness of the cathode-ray tube spot, integrated over its area, may to the first order be taken as proportional to the square of the applied grid voltage. If the final record is to be proportional to the logarithm of the power of the signal, the detector law should be linear.

The need for a linear detector is in conflict with the square-law requirement for accurate background subtraction, but a compromise solution with linear detection is considered tolerable.

The use of logarithmic amplifiers is one means of ensuring a very great dynamic range of the receiver. This law is not, however, best suited to intensity-modulated film recording, since the ultimate record then possesses "log-log" characteristics and records of high-level activity become degraded by granulation noise, in comparison with low-level activity. Logarithmic amplifiers are, however, suited to linear—for example, digital—recording systems, such as magnetic-tape and digital-photographic recording.

267 Fine-Structure Spectrograph

The introduction of special spectrographs for studying the fine structure of solar bursts was due mainly to Elgaroy, whose swept-frequency spectrograph at Oslo covers the frequency range of 200 to 230 MHz with a scan rate of 50/sec. Several others have since been made, including a major multichannel instrument in the Netherlands which operates with 60 fixed channels between 160 and 320 MHz. The development of multichannel instruments is a natural consequence of the need for maintaining sensitivity while increasing the time or frequency resolution. As still higher

frequency resolution over a not-too-restricted frequency range is sought, hundreds of channels are required, and the task of building multichannel instruments becomes increasingly forbidding.

An alternate way of forming the spectrum simultaneously is to record the radio-frequency voltage waveform due to the summation of all frequencies in the band and then obtain the spectrum by using a computer to calculate the square of the Fourier transform; however, the recording rate is at present prohibitive, except for very restricted bandwidths.

A further possibility is the use of optical processing. The theory of this technique was discussed a few years ago by Lambert. Recently, Cole has made some experimental tests that seem to demonstrate that the technique is completely feasible—see paper by Cole (Australia) below .

SATELLITE-BORNE SPECTROGRAPHS

T. R. Hartz (Canada)

The radio spectrographs aboard the Alouette 1 and 2 satellites have been used for solar-burst observations, even though these instruments were not designed explicitly for this purpose, having been designed as receivers for the topside sounders. A number of Type III solar bursts have been observed and correlated with ground-based observations. These bursts span the full range of the satellite receiving system down to 600 KHz. Time delays of 1 to 2 min are observed between the onset of the bursts at 20 MHz and at 1 MHz. Type III bursts in the 1-MHz frequency range decay with a time constant of a few minutes. This decay time is much shorter than would be anticipated on the basis of thermal decay.

THE ELECTRO-OPTIC INSTANTENOUS SPECTROGRAPH

T. Cole

A new type of spectrograph, which achieves continuous coverage in both frequency and time, has been constructed in Sydney. It uses the interaction of coherent light from a laser with a beam

of ultrasonic sound. For a sinusoidal sound beam in a transparent medium, there are alternate regions of compression and rarefaction. Light propagating parallel to the sound-wave front and entering a rarefied region travels faster, because of the lower refractive index of the rarer medium, and so emerges advanced in phase, with respect to light traversing the denser section. That is, under certain conditions, one has an optical phase grating. Phase gratings, like all gratings, produce a series of defraction orders given mathematically by a Fourier transformation. The angular intensity distribution of the immergent light is thus directly related to the spectrum of the incoming electrical signal. To fully utilize the multichannel nature of the system, a multichannel detecting device, such as a photographic plate or television tube, must be used.

REVIEW PAPER

H. Urbarz (Germany)

The new solar radio spectrometers operating in the frequency range from 46 to 540 MHz at the University of Tübingen were described.

REVIEW PAPER

W. L. H. Shuter (Canada)

A multipurpose radio spectrometer, for operation in the 1 to 4 GHz range, is being constructed as a joint project by the University of British Columbia and the Dominion Radio Astrophysical Observatory. The spectrometer can be tuned to any one MHz band, within the above range, in order to search for spectral lines. The output will contain 100 channels, each 10 KHz wide. This instrument will be used to study any spectral lines of astrophysical importance, and, in particular, it may be used to look for the solar line at 1,057 MHz caused by the $^2P_{1/2}$ - $^2S_{1/2}$ transition or to search for recombination lines in the solar atmosphere.

REVIEW PAPER

J. P. Hagen

The development of a solar flare, in terms of an outward moving disturbance, was described on the basis of observations at 10, 3, 1, and 0.3 GHz.

REVIEW PAPER

M. R. Kundu

A 32-element grating array, operating at 612 MHz, with a fan beam of 2!8 ft width, has been used for observations of the brightness distribution of the quiet sun. The new observations agree with theoretical brightness distributions for the solar disk, but disagree with the older observations of O'Brien and Tandberg-Hanson.

REVIEW PAPER

A. Boischot

A new 16-element grating array operating at 408 MHz was described. The beamwidth of this instrument is 1!7. The instrument is being used to observe the distribution of emission from centers of activity.

INTERPLANETARY OBSERVATIONS WITH THE USE OF RADIO TECHNIQUES

A. Hewish (U.K.)

Radio methods that currently enable useful data to be obtained on the interplanetary medium may be listed as follows:

1. Measurements of the angular spectrum of radio waves from sources outside the solar system. These yield data about irregularities of electron content in interplanetary space.

2. Interplanetary scintillation. The drift motion and spatial correlation of interplanetary diffraction patterns may be studied with the use of spaced receivers. This gives information about the solar wind and the sizes of plasma irregularities in space. Observations of the correlation of the patterns at different frequencies can also be used to study independently the "phase thickness" and scale size of the irregularities.

3. Measurements of the differential group path between the earth and deep-space probes yield data on both the integrated electron content and on temporal and spatial fluctuations of plasma density at the probe location.

Published results obtained with method (3) are, so far, of a preliminary nature, and this note is confined to a discussion of the achievements, possibilities, and limitations of methods (1) and (2).

In view of the increasing volume of data now becoming available from space probes, it is important to see what purely ground-based radio techniques can add. First, radio methods are not confined to the ecliptic plane and to radial distances of about 1 AU, as they have been for most space probes. Second, by depending upon integration along a line of sight through the interplanetary medium, radio methods are likely to yield a better overall view of the entire region than can be gained from data obtained at a single point. A study of the dependence of the solar wind upon radial distance and heliographic latitude, for example, would be of great importance, and it now seems that this is feasible. Third, radio measurements give an indication of irregularities on a much smaller scale than can be detected by other means at the present time. They are likely to be of value in studying plasma instabilities, hydromagnetic waves, etc.

Method 1

Measurements of the angular spectrum of the scattered radiation have been carried out extensively since 1952, and, combining many observations (Vitkevitch et al., Hewish, Slee, Blum, Boischot, Hogbom, Gorgolewski, Wyndham, Erickson, Kundu, Squeren-Malinge, and Okoye), lead to the following general conclusions:

1. Plasma irregularities are a permanent feature of the interplanetary medium to at least 0.5 AU from the sun.

2. The scale of the irregularities is less than 5,000 km at 0.3 AU (scales a factor of 10 smaller than this are revealed by interplanetary scintillation).

3. A systematic variation of scattering with the solar cycle takes place at all radial distances. A decrease by a factor of about 5 has occurred between 1959 and 1964.

4. There was a marked scattering anisotropy, indicative of radially aligned filaments, during sunspot maximum. The effect is much reduced at sunspot minimum.

5. Scattering falls off slowly with radial distance from the sun, the radial-power law index varying from about -3 at 0.05 AU to -1 at 0.3 AU.

6. Close to the sun (within 10 solar radii), both increases and reductions of integrated flux take place that are not yet adequately explained.

7. The scattering irregularities are less pronounced at high heliographic latitude.

These results are in general agreement with the space-probe picture of an over-all solar wind, carrying with it a system of co-rotating magnetic filaments. The progressive decrease of slope of the radial variation is of interest, however, and should give information about the origin of the small-scale irregularities. In other words, are the irregularities imposed upon the medium near the solar surface and convected outwards, or do they correspond to instabilities which may develop progressively as the plasma drifts through space ?

In extending measurements of the angular spectrum to still larger radial distances, it is of great importance to know where multiple scattering (imposed phase irregularities larger than 1 rad) reverts to single scattering. Simultaneous observations of interplanetary scintillation at different frequencies have recently shown that the interplanetary medium is "phase-thin" beyond 0.5 AU at a frequency of 80 MHz. It would appear that frequencies of 10 MHz or less are needed, if the assumption of multiple scattering is to be valid at radial distances of the order of 1 AU.

Method 2

The discovery of interplanetary scintillation has provided a new and extremely sensitive technique for studying plasma irregularities in space. Recent observations have already enabled plasma irregularities to be detected at distances of about 1 AU. Measure-

ments of the spatial and temporal correlation of the diffraction pattern, with the use of spaced receivers, allow both the scale of the irregularities and their motion to be studied, while simultaneous measurements at different frequencies enable estimates to be made of the "phase-thickness" of the diffracting region.

It has already been shown that the irregularities have the remarkably small scale of around 200 km. The fluctuations of plasma density are, therefore, on a scale little larger than the proton gyro-radius, and this raises interesting questions concerning their origin.

When deriving irregularity scale sizes from diffraction patterns caused by interplanetary scintillation, it must be remembered that only irregularities smaller than the Fresnel-zone radius will give rise to intensity fluctuations at a given distance from the scattering region. At 100 MHz irregularities larger than about 1,000 km, for example, would give little scintillation at 1 AU. It follows, that scintillation measurements need to be augmented by angular spectrum measurements in order to gain a complete picture of the interplanetary medium. Recent data on the angular spectrum of the scattered radiation at 38 MHz, at a distance of 0.5 AU. suggest that only about 50 percent of the total phase irregularities have the small scale derived from scintillation measurements.

The motion of the scintillation-diffraction pattern over the ground has been studied at Cambridge with the use of spaced receiving sites. For a period of about five months in 1966, the measured velocity vector corresponded to a radial outflow of plasma from the sun at speeds varying from 310 km/sec to 450 km/sec. These results give the first indication of a solar wind at high heliographic latitude and suggest that the velocity over the pole exceeds that in the ecliptic plane. Extended observations at varying radial distances and at heliographic latitudes should yield a far more complete model of the solar wind than is currently available from space probes.

It is interesting to note that decametric radiation from Jupiter also appears to give rise to interplanetary scintillation. Intensity patterns drifting at speeds appropriate to a solar wind were reported by Douglas in 1963, while Slee has recently obtained data on the scale of the patterns that are consistent with the values obtained from observations of 3C 48.

REVIEW PAPER

F. D. Drake

The scintillation of small-diameter radio sources caused by irregularities in the interplanetary medium has been considered by Salpeter. In the weak-scattering case (phase deviations less than 1 rad), the probability distribution of the scintillation index is symmetrical, and the cross correlation of scintillations over large frequency ranges is good. In the strong-scattering case, the probability distribution of the scintillation index is markedly skew and the cross-correlation frequency is bad. Observations made at Arecibo at 40, 195, 430, and 611 MHz essentially confirm the theory. Strong scattering usually occurs when radio sources are in close proximity to the sun. Also, after solar flares, the scintillation index can increase by a factor of up to 10.

Recent diameter measurements of some of the radio sources are as follows:

Source	Percentage of Source Scintillating	Size of Source (second of arc)
3C 138	100	0.1
3C 245	30	< 0.05
3C 267	30	< 0.1
3C 273B	30	< 0.2
CTA 102	100	< 0.1

INTERPLANETARY AND TERRESTRIAL WAKE ELECTRON NUMBER DENSITY MEASUREMENTS WITH PIONEER 6 AND 7

V. R. Eshleman (U.S.A.)

Measurements of the interplanetary electron density, averaged over a base line from 35 to 100 $\times 10^6$ km from the earth, yield a result of 6.1 electrons/cm^3 with a temporal rms deviation of 2.5 electrons/cm^3. While these measurements were in progress, from April through June 1966, there was relatively little solar activity. A higher density of 8.0 ± 4.0 electrons/cm^3 was measured during a period of relatively high solar activity from February 20 to April 9, 1966, over a base line from 10 to 35 $\times 10^6$ km from the earth.

Second Business Meeting

CHAIRMAN: W. N. CHRISTIANSEN

Secretaries

The present secretaries, J. L. Steinberg and J. W. Findlay (U.S.A.), were unanimously re-elected.

Subcommissions and Committees

1. An International Radio Astronomy Observatory. In the absence of Dr. J. Bolton, Professor Hagen reported on the status of a report from this committee, which was set up at the 14th General Assembly. The report needs more work, particularly in considering possible sites and in making cost estimates. Professor Hagen suggested that a similar group be formed in the International Astronomical Union so that the study would be known to both unions. Sir Bernard Lovell said that the whole idea needed very careful thought. The time scale would be long, the cost high, and the possibility of interference with national and regional developments considerable. After some general discussion, it was agreed that the committee should continue its work.

2. The Calibration of Solar-Flux Density. The following working group was set up to study and report on the absolute calibration of the flux of radio waves from the sun:

H. Tanaka, Chairman (Japan)
A. E. Covington (Canada)
H. Daene (Germany)

A. D. Fokker (Netherlands)
A. Moltshanov (U.S.S.R.)
T. Takakura (Japan)

3. Subcommission V(e). It was agreed that this subcommission had now completed its task and that its duties were being very well continued by the IUCAF, under Professor F. G. Smith. The thanks of Commission V were given to the subcommission, and it was dissolved.

Symposia

Subjects for a possible symposium were requested. None were forthcoming at the meeting; it was suggested that proposals should be made to one of the Commission V secretaries.

Resolutions

1. On the Allocation of Frequencies for Radio Astronomy. The following resolution was approved by Commission V:

Commission V of URSI supports and encourages the work of IUCAF in securing and seeking to improve the frequency allocations for the radio astronomy service, but notes:

(a) The series of frequency bands for observations of the continuum of cosmic radio waves is seriously incomplete, no band being allocated on a secure and worldwide basis between the bands 37.75 to 38.25 MHz and 1,420 to 1,427 MHz.

(b) Recent observations have emphasized the need for improved protection of the natural frequencies of the OH radical.

Commission V urges IUCAF:

(a) To press for improved and worldwide protection in the frequency bands for observation of the continuum of cosmic radio waves and, in particular, the band 322 to 329 MHz, which is needed also for observation of the natural line radiation from deuterium.

(b) To support the recommendation of CCIR (Oslo, 1966) concerning the protection of frequencies for observations of the natural line radiation from the OH radical.

(c) To study the need for extending the protection of observations of the natural line radiation from the OH radical to include appropriate bands at approximately 1,612.2 MHz and 1,720.5 MHz.

2. On International Exchange of Radio Astronomers. A letter from Dr. Varsavsky of the Argentine was read, in which he asked Commission V to consider a scheme for making easy the interchange of workers in radio astronomy, particularly between countries where the science was less well developed and other countries. In general, the discussion was favorable toward the idea, but it would need consideration, in the light of interchange schemes already working in some countries. It was agreed that Dr. Bolton's committee (above) should work on the idea, and Dr. Hagen agreed to forward Dr. Varsavsky's letter to Dr. Bolton.

3. On the Terms of Reference of Commission V. Professor Hagen read a draft of a possible resolution to define more clearly the functions of Commission V, particularly with respect to radar astronomy. It was agreed at the meeting that such clarification might be needed. However, a consideration of the terms of reference of Commission V, as agreed upon at the 13th General Assembly at London, showed that these are still satisfactory and that no further action was needed.

New Radio Telescopes and Galactic Radio Astronomy

CHAIRMAN: M. CECCARELLI (ITALY)

New Radio Telescopes (Brief Presentations)

K. Akabane (Tokyo) described several new radio telescopes in Japan. A 24-m spherical reflector has been built in cooperation with the Japanese Radio Research Board. This instrument has been used for studies of the 21-cm hydrogen line. A contour diagram was shown of neutral hygroden in the region of IC 443. Two antennas, of 22-m and 30-m diameters, have been built in Japan for space-communications experiments, and these have been used for some radio-astronomical observations at about 4,000 MHz. The 30-m antenna has been used for a study of 20 galactic sources. Maps of W44 and W51 were shown; W51 has two components, and nonthermal emission is observed in the northerly part of these components.

At the Tokyo Observatory, an eight-element grating interferometer has been built for solar observations at 17 GHz.

E. Blum (Paris) reported observations of galaxies in the 21-cm hydrogen line, using a multichannel receiver on the large telescope at Nançay. These observations have been described by Delannoy and Weliachew (Compt. Rond., 262, 1640; ibid., 263, 223). A moving feed was used to track four galaxies for periods of 25 min each (NGC 3109, NGC 2403, NGC 4490, and NGC 5457); the tracking feed was not perfectly adjusted, and there were problems with galactic hydrogen emission entering through excessively high spillover lobes. The receiver has a 4.2 MHz bandwidth divided into 16 channels. Dual parametric amplifiers are used in a correlation scheme, giving a system temperature of 350°. Output is on punched tape. A program is now underway to make similar measurements on 150 galaxies.

R. Bracewell (Stanford University) described a proposal to construct an array consisting of five antennas having 18.3-m diameters, arranged in a grating configuration with a unit spacing of 22.9 m. Operating at λ = 2.8 m, the array would have a 17-sec fan beam with a 4.2-min spacing between grating lobes. The antennas in this array would be paraboloids of a novel design, achieving high surface accuracy at modest cost. A prototype dish is now complete.

M. Ceccarelli (Bologna) described the present state of the Northern Cross. The E-W arm has been in operation for 2 years. At a frequency of 408 MHz, it has a fan beam with dimensions $4.2^\circ \times 4$ min; the confusion limit is 0.2 flux units (fu). A survey is now under way, and some thousand sources have been catalogued. The N-S arm will be in operation in about 6 months, giving multiple pencil beams. The total collecting area will be 18,000 m^2. A second, off-axis feed is planned on the E-W arm. This will have phase shifters so that it may be steered in hour angle as well as declination.

N. Christiansen (Sydney) described two grafting interferometers, one in Australia and one in China. At Fleurs, Australia, the 32 × 32-element criss-cross has been converted into a pair of compound interferometers by adding two 14-m dishes at the end of each arm and completely new electronics. Earth-rotation synthesis will be used, with tracking only over ± 4 hours (limited by the mounts on the 6-m dishes of the original cross). The completed instrument will have 40-sec resolution over a 1° field, and will have a sensitivity of 2-3 × 10^{-28} mks.

The new interferometer to be built near Peking will also be a grating interferometer using earth-rotation synthesis. Twenty 6-m dishes will be used in a widely spaced grating, with the grating lobes suppressed by switching against a compact group of eight similar dishes located at the center of the wide-spaced grating. The operating frequency will be about 200 MHz, giving a resolution of about 4 min.

M. Kundu (Bombay) told of progress on the Indian radio telescope. This is a 500 × 30-m cylindrical paraboloid mounted with its axis parallel to the earth's. A suitably inclined hillside has been found in southern India (latitude about 12°), and erection of the steelwork is about to begin. The feed configuration will be similar to that used on the Bologna cross. The main program will be a survey of

faint sources, using lunar occultations. The antenna will track ± 65° in hour angle and ± 35° in declination. Eleven beams, each about 2.5° x 8 min will be formed, separated by 4 min in declination. These will be steered to follow the moon for 8 hours per day. The operating frequency will probably be 325 MHz.

J. Locke (Ottawa) gave some details about the new 46-m telescope at the Algonquin Radio Observatory. The instrument is on a mount similar to that of the Parkes telescope, with fine tracking guided by a master equatorial. Either prime or Gregorian focuses may be used. Optical measurements give an rms deviation of the surface from a true paraboloid of only 1 mm. Radio tests have been made with a prime-focus feed and a tunnel-diode receiver at 2.85 cm. The aperture efficiency near the zenith is 40 percent, falling to 30 percent at 75° zenith angle.

C. Mayer (U.S. Naval Research Laboratory) told of measurements on the new high-precision 25-m telescope at the Maryland Point Observatory (for a description of the instrument, see Sky and Telescope, July 1966). Measurements between 1 cm and 3 cm have given the following results:

λ (cm)	Efficiency	Gain (dB)	Beamwidth (min)
3.15	0.57	66	5.0
2.07	0.50	69	3.3
1.55	0.45	71	2.5
0.95	> 0.20	> 72	≈ 1.5

The change of efficiency with wavelength indicates an over-all rms surface accuracy of 0.75 mm. At 1.55 cm, the gain changes by less than 10 percent in going from the zenith to a zenith angle of 60°. The pointing accuracy is better than 30 sec.

P. Mezger (Green Bank) described measurements of the performance of the 43-m equatorial telescope at short wavelengths. Limits are set by large-scale deflections, by random errors in the surface, and by atmospheric effects. He emphasized that the telescope is successful, in that it meets its design specifications; however, it is unlikely that any other equatorially-mounted telescope of comparable size will ever be constructed.

Large-scale deflections cause changes in gain and focal length as the telescope is moved away from the zenith, and several slides were shown to illustrate these changes. The total range of

focal lengths is about 2 cm. Even with refocusing, the change of gain at $\lambda \approx 2$ cm is more than a factor of 2 in going from the zenith to zenith angles of about 55°.

Random errors cause a drop in aperture efficiency at short wavelengths. Following the theoretical treatment of Ruze, the random errors can be described by a correlation length ℓ and a mean-square phase error δ^2. If the mean-square surface error is d^2, then $\delta^2 \approx 16\pi^2 d^2/\lambda^2$. The aperture and beam efficiencies vary with wavelength as:

$$\eta_A(\lambda) = \eta_{A_o} e^{-\delta^2} + C_1 \qquad \text{(aperture efficiency),}$$

$$\eta_B(\lambda) = \eta_{B_o} e^{-\delta^2} + C_2 \qquad \text{(beam efficiency).}$$

For the 43-m antenna at the zenith, an rms deflection of 0.92 mm gives the best fit to the observed data on efficiency versus wavelength.

The atmosphere may affect the performance of the telescope in several ways. The structure distorts somewhat with changing temperature, giving rise to a change of focal length; the range is 8 mm for a 50° C range of temperature. Thus, there is a new and important aspect of the term "antenna temperature." Irregularities in the atmosphere above the telescope may also limit its performance by refracting or causing loss of coherence in the waves from the source. The performance of the 43-m telescope does not seem to be limited by this type of atmospheric effect.

A. Moffet (California Institute of Technology) reported on the new interferometer which has been proposed for the Owens Valley Radio Observatory. It will consist of eight 40-m altazimuth telescopes mounted on a 3 × 5-km rail system. The first of these telescopes is now under construction and will be completed by the summer of 1967. The reflector surfaces are expected to be usable at the 3-cm wavelength.

With eight elements, 28 pairs are available, and correlators will be provided for each pair. The pointing of each antenna and adjustment of delay lines and fringe rates will be taken care of by a single on-line computer. Operator information, such as time and coordinates, will be displayed on a cathode-ray tube display generated by the computer. The computer will also collect data from each correlator and may perform real-time

analysis for some of the simpler types of observations. In other cases, the computer will record the data on magnetic tape for subsequent analysis by a more powerful machine.

The interferometer is planned to have maximum flexibility, both in the configuration of the array and in the details of signal processing. A frequently used configuration will be a linear array giving two-dimensional brightness distributions by earth-rotation synthesis. If the eight elements are placed to give minimum redundancy, 23 multiples of a unit spacing may be obtained at once. Used at the 10-cm wavelength, this configuration would give a picture of an area 5 min in diameter with a resolution of 10 sec or less. At 3 cm, resolutions approaching 1 sec could be obtained.

C. Muller (Dwingeloo) described progress on the new synthesis telescope at Westerborg, about 20 km northeast of Dwingeloo. This will consist of twelve 25-m telescopes on equatorial mounts. Ten of these will be fixed with a unit spacing of 144 m, while two will be movable on a 300-m track at one end of the array. The size of the synthesized beam will be 23 sec at the 21-cm wavelength.

Data collection will be under control of an on-line computer. Each antenna will have orthogonal feeds and two paramps giving an over-all bandwidth of 4 Mc/sec. Signals from the two movable antennas will be correlated with those from the 10 fixed antennas, taking all combinations of parallel and crossed dipoles.

All foundations are now complete. The first antenna will be complete in mid-1967, with an additional one completed each 6 weeks after that. The full array should be in operation in about 2 years.

H. Tanaka (Nagoya) spoke about results obtained with several new solar telescopes at the Toyakawa Observatory. A compound interferometer operating at 9,400 MHz is composed of thirty-two 2-m dishes and two 3-m dishes. This gives a one-dimensional resolution of 21 sec. An N-S arm of sixteen 1.2-m dishes is being constructed as well; when used with the 32-element grating as a tee, this will give 1.5-min pencil beams. Rotary phase shifters will be installed to give rapid scanning of the beam in declination. Several examples were shown of observations with the compound interferometer.

A similar compound interferometer for operation at 8 cm is also under construction. It will have an over-all base line length of 437 m. A two-element interferometer is in use for location of solar bursts at the 30-cm wavelength.

P. Wild (Sydney) reported on the new radio heliograph at Culgoora. It consists of ninety-six 13-m antennas arranged in a 3-km diameter ring. Signals from the 96 telescopes will be combined, using the method of J^2 synthesis described in an earlier session. The field of view will be 2° at the zenith, with a resolution of 3.5 min. The operating frequency is 80 MHz, with a bandwidth of 1 MHz. The signal processing system will produce a picture having 48 × 60 picture elements once per second in each of two polarizations. These will be displayed and also stored in digital form on magnetic tape. An optical signal-processing system giving continuous coverage of the whole field is under consideration. First operation of the telescope is expected in April 1967.

R. Aitchinson (Sydney) reported briefly on an analog technique for producing multiple beams in large interferometer systems. In the system developed by M. Large and R. Frater, four outputs from each i.f., having relative phases of 0°, 90°, 180°, and 270°, are combined by adding appropriate fractions in resistive networks.

Galactic Radio Astronomy

F. Kerr (Maryland) reviewed the IAU-URSI symposium on radio astronomy and the galaxy which was held at Noordwijk, Netherlands, August 25 to September 1, with 85 invited participants. The reports at the symposium were presented under three major sections: (1) interstellar clouds; (2) large-scale distribution and the motion of interstellar gas; and (3) the galaxy as a radio source; magnetic fields. Generally, one or more general review papers were given under each section, with comments and short papers by many participants.

The first review was by H. van Woerden on observational data on cloud structure. Progress in this field has been slow, and knowledge of the gas structure is still uncertain. There is some doubt that clouds, as such, exist in quantity; most of the hydrogen may exist as a slowly varying distribution with little structure being evident.

Observations of OH form a more active field and many major mysteries exist in both the OH emission and absorption. The general OH observational situation was reviewed by Robinson; some theoretical problems were considered by Salpeter.

In the field of OH emission, interferometer measurements have shown that individual emission sources are less than 20 sec in diameter, although it was noted that, if the sources are coherent, the wrong angular diameters will be derived. For observed antenna temperatures, these small diameters lead to brightness temperatures from 10^5 to even 10^6 deg K. Barrett discussed the fact that the frequencies of the OH lines are still inconsistent to an extent of a few kilocycles per second. Under the heading of "large-scale motion and distribution," P. O. Linblad reviewed the motion and distribution of neutral hydrogen and discussed the problems connected with the rotation curve and the large-scale deviations from circular motion. How to improve the older map of the hydrogen distribution is not yet clear. New extensive hydrogen observations for limited ranges of latitude were presented from Parkes and Green Bank. Varsavky displayed a new rotation curve and showed how differences in bandwidth and beamwidth can affect the observational results. Schmidt-Kaler discussed the evidence for galactic structure derived from young objects observed optically. Observations of hydrogen in M 31 were considered to see what they could tell us about our own galaxy. Many analogies between the two systems were evident.

Margaret Burbidge reviewed the properties of H II regions in our own and other galaxies. Much attention attached to Mezger's discussion of the hydrogen recombination lines of high quantum number that occur throughout the radio spectrum. Many exciting new research possibilities in galactic motions and the astrophysics of H II regions exist through studies of these lines.

At the Noordwijk symposium, F. Kerr reviewed the observational evidence delineating the complex structure of the galactic center. Interesting new developments in this field are that most of the high-velocity hydrogen seems to suggest the characteristics of a bar of a barred spiral. Also, there appear to be two jet-like features coming out of the center of the galaxy, at a sharp angle to the galactic equator. These jet-like features have been traced in the continuum at Parkes and in H I observations at Leiden. The relation of H and OH in the direction of the galactic center remains a difficult problem.

Lequeux discussed the structure of the continuum source Sagittarius A and Pickelner tried to outline a theoretical interpretation of the phenomena at the center.

Blaauw and Oort discussed the observations of hydrogen clouds with moderate and high velocities at latitudes well away from the

Milky Way. Their interpretation is that this material is falling in from outside the galaxy; other hypotheses were suggested in the discussion.

Baldwin gave an excellent review of the various components of the galactic nonthermal radiation, its relation to spiral arms, its relation to supernova remnants, its spectrum, and so forth. The question of the existence of a galactic halo remains unanswered. Some conference participants favored an extensive halo, others favored no halo, and Ginzburg drew a distinction between a physical halo and a radio halo. The physical halo, Ginzburg said, is the transition from the galactic disk to extragalactic space, and must be present, regardless of any observable radio halo. The question of a halo is much confused with problems of galactic spirals.

Van de Hulst considered methods of observing a galactic magnetic field. Most information of this topic comes from radio polarization measurements. The existence and local orientation of the field are established, but details are not clear.

Ginzburg reviewed the origin and evolution of cosmic rays. He favors a galactic origin for the high-energy cosmic ray particles. G. Burbidge spoke in favor of a metagalactic origin, but later seemed convinced that galactic origin was more probable.

Recent advances in x-ray astronomy were reviewed by Rossi. Much discussion centered on the possible identification of the Scorpius XR-1 source with an old nova, probably within a distance of 100 parsecs.

In a second paper, F. Kerr spoke about the coming series of lunar occultations of the region of the galactic center. The present inclination of the lunar orbit is such that the moon will, for some time, cross the region of the galactic center at each lunation. Advantage should be taken of the opportunities thus presented, during the period 1967 to 1970, for high-resolution studies of all aspects of the galactic center. Such favorable opportunities will not occur again for 19 years. The coming observation possibilities will be especially favorable in the northern hemisphere; they will be much less favorable in the southern hemisphere. Plans for observations should be made soon; the moon is already far enough south to make it feasible to start some tests.

Rupert Clark of Sydney has prepared predictions for a number of stations and could include others. Kerr expressed a keen interest in hearing from any individuals interested in making occultation observations of the galactic-center features during the next few years.

H. Weaver (Berkeley) showed the results of an OH survey in the direction of the galactic center made at Hat Creek and spoke about an interpretation of the broad OH features. He pointed out that the broad OH absorption lines must arise in structures quite different in character from those that give rise to the three narrow lines at zero velocity, -30 km/sec, and -53 km/sec. In the 3-kiloparsecs arm, for example, the OH/H ratio is of the order of 10^{-6}, while in the unidentified structures, from which the broad lines originate, the OH/H ratio is 10^{-4}.

The velocity field of the OH-rich features was displayed by showing a series of OH profiles taken every half-beamwidth (every 0.25°) along b = -0.25°, and by showing an ℓ, v contour map for b = -0.25°. In the ℓ-range of 358.5° to 4.0°, more than 10 OH-rich features appear. As a function of longitude, a feature at a particular velocity will appear weakly, grow stronger, to some maximum value, and fade away. However, as it waxes and wanes, as a function of longitude, a given feature always retains the same velocity. At any given longitude, several features, at different stages of intensity development, may overlap.

A telescope beam, swinging in longitude, appears to sweep over a series of randomly-placed OH-rich regions. Characteristically, an OH-rich region has an angular diameter at half intensity of possibly 15 to 20 minutes of arc. It has a fixed velocity. The line arising from such a region has a characteristic half velocity at half intensity of the order of 30 km/sec. The triangular shape of a spectral line arising from an OH-rich region is not characteristic of turbulence or of expansion with conservation of material. It can be accounted for by expansion of OH gas without conservation of material.

Weaver suggested that an OH-rich region might arise in the volume surrounding a star in the earliest stages of birth. Commencement of radiation-energy generation could cause the destruction of the intersteller grains remaining after star formation. Such destruction would be accomplished with the formation of a large percentage of OH (and other) molecules, hence the abnormally large OH/H ratio. The gas would be driven out from the star by stellar winds and/or radiation pressure, giving rise to the wide lines of the shape observed. Attention was drawn to the existence of many T Tauri stars (the youngest optical objects known) in the region of the sky in which the OH-rich regions are observed. The T Tauri stars are associated with the general Ophiuchus complex of dark clouds; reasons were given for assuming that the OH

regions might well be associated with the same complex of dark clouds in the direction of the galactic center, about 100 to 150 pc from the sun.

M. Kundu (Bombay) described observations of the Cygnus Loop made at Arecibo at frequencies of 430, 195, and 41 MHz. At these frequencies, the beamwidth is 17, 35, and 144 min, respectively. The resolution achieved (especially at 430 MHz) made it possible to study many more structural details of the loop than had been observed previously and to study the variations of spectral index from one part of the loop to another.

In the main loop, four principal sources (some of which are resolved into more than one component) are found. The over-all shape of the radio source and its various components resembles the optical picture of the loop. In particular, one can see two separate regions—the main loop and the region of NGC 6992 to NGC 6995.

Observed variations in spectral index may be related to variations in physical conditions in different parts of the object. The data on spectral index thus provide information on the evolution of different parts of the loop and insight into the mode of formation of different components of the source. In particular, the observational results have been compared with van der Laan's theory of the interaction between a supernova remnant and the interstellar medium. Van der Laan showed that the expansion of the supernova's envelope into the interstellar medium is accompanied by a shock wave that propagates ahead of it. A compressed region outside the ejected envelope is formed. This region acts as a source of synchrotron radiation. The differential energy spectrum of the electron-positron component of the relativistic gas in the compressed region remains the same as it is in the unidsturbed interstellar medium, but there occurs an enhancement of volume emissivity, owing to the compression of the magnetic field and to the increased number density within the relativistic gas. Comparing the spectra of regions of the loop with the spectrum of the galactic halo, Kundu finds displacement of loop spectra to higher frequencies in agreement with theory.

Extragalactic Radio Astronomy

CHAIRMAN: A. T. MOFFET

EXTRAGALACTIC RADIO ASTRONOMY

A. T. Moffett

I propose to divide, rather arbitrarily, extragalactic radio astronomy into the categories of: (1) "Normal galaxies," including line and continuum emission; (2) "strong discrete sources," (the radio galaxies and quasi-stellar sources); and (3) "cosmic background emission."

Normal Galaxies

Continuum Emission. The largest radio telescopes can now detect continuum emission from many of the closest normal galaxies. A few of the nearest galaxies can be well resolved by existing pencil or fan beams. Active work in this area has been carried out at Jodrell Bank, Ohio State University, Green Bank, Parkes, and Mongolo.

At Green Bank, Heeschen and Wade have surveyed 515 northern galaxies brighter than $M_{pg} = 11.2$. Of these, they detected 88 at either 750 or 1,400 MHz. With the exception of the previously known radio galaxies in their sample, most of the objects detected were late-type spirals or irregulars.

It seems possible to separate normal galaxies from abnormal radio galaxies at a radio luminosity of about 10^{40} ergs/sec.

Below this level, we find mostly normal spirals or irregulars; above are the radio galaxies, which are mostly peculiar ellipticals. There seems to be a fairly sharp division between elliptical radio galaxies, with L between 10^{40} and 10^{45} ergs/sec, and the normal elliptical galaxies, which have undetectable radio emission, $L < 10^{36}$ ergs/sec.

The distribution of continuum emission in normal spiral galaxies seems to vary a great deal. Some, such as M 31, have extensive radio halos, while others recently studied at Parkes and Mongolo have their radio emission concentrated in the vicinity of their nuclei. The number of galaxies studied is still too small to draw conclusions about the relative frequency of the different types of distribution. Burbidge and Hoyle have suggested that radio halos around normal galaxies may be transient phenomena produced by occasional violent outbursts from the galactic nuclei. It is presumed that the radio emission from normal galaxies is synchrotron radiation from the electron component of the cosmic rays within these galaxies. Thus, the distribution of radio emission reflects the distribution of cosmic rays or magnetic fields, or both.

Line Emission. The 21-cm hydrogen emission from M 31 has been studied in some detail at Jodrell Bank, Ohio State University, and Green Bank. A hydrogen envelope extends considerably beyond the visible limits of the galaxy, while there seems to be an absence of neutral hydrogen in the nucleus. There is good correspondence between concentrations of neutral hydrogen emission and the outer spiral arms, as outlined by strong ionized hydrogen regions. Rather similar results have been obtained for M 33.

Hydrogen line emission has been detected from several dozen other spiral and irregular galaxies. Rotation curves have been obtained for many of the nearer ones, with the use of pencil-beam antennas, mainly at Green Bank, Harvard College Observatory, and Nançay. The Owens Valley Radio Observatory interferometer has been used to obtain rotation curves for a number of more distant galaxies having angular diameters in the range of 3 to 10 min.

Extensive studies have been made at Parkes of both the line and continuum emission for the Magellanic Clouds. These have led to the reclassification of the Large Cloud as a barred spiral, rather than an irregular galaxy. The first extragallactic supernova remnants have also been detected in the Large Cloud.

Strong Discrete Sources

The subject of discrete sources has been reviewed at the preceding two general assemblies—by Bolton in 1960 and by Ryle in 1963. Since these lectures, we have added much to our knowledge of the structure and physical properties of the radio galaxies, and we have opened up the whole subject of the quasi-stellar sources.

Radio Galaxies. As I have indicated above, these are galaxies with abnormally strong radio emission, having radio luminosities $> 10^{40}$ ergs/sec. Their luminosities range upward to about 10^{45} ergs/sec. The most remarkable feature of radio galaxies is their similarity.

The radio spectra of radio galaxies conform very well to a power law with a spectral index of about -0.75. In some instances, the spectrum is observed to steepen at wavelengths shorter than 10 or 20 cm; in a few instances, there is a cutoff at meter or decameter wavelengths.

The structures of radio galaxies are very similar. Most are elongated double sources with two major, rather symmetrical regions of radio emission; a minority have a small bright core (which may be double) surrounded by a diffuse, larger diameter halo. The number of radio galaxies with other types of structure is almost negligible. An interferometric study has just been completed by Fomalont with the Owens Valley interferometer at 21 cm. He has resolved about 200 sources, of which 100 have diameters greater than 2 min, so that their structures may be well determined with the available spacings. Of these, 40 percent are "classic" doubles, 30 percent have weaker third components, and 30 percent have core-halo structures. A smaller number of southern sources have been studied by Ekers, using the running-base-line interferometer at Parkes. Ekers confirms the predominance of double sources among the radio galaxies.

Higher resolution studies carried out at Cambridge and Green Bank have produced detailed brightness distributions for a few radio galaxies. These suggest that the components of the double radio sources, when studied with very high resolution, may break up into a number of smaller knots of high surface brightness. Wade finds that as much as 90 percent of the 11-cm flux from Cygnus A may come from five or six such concentrations.

The polarization of radio sources has been studied extensively in the past three years. Almost all radio galaxies show some

degree of linear polarization at wavelengths of 30 cm or less. The degree of polarization ranges from a few per cent to as much as 40 percent. Soboleva and her co-workers at Pulkova, and Seielstad at Owens Valley, have shown that the polarized emission virtually always comes from a smaller volume within the source than that which produces the unpolarized emission. The large regions of regular polarization found in the Parkes observations of Centaurus A and Fornax A presumably imply large-scale regularities in the magnetic field within these sources, assuming that the observed emission is synchrotron radiation. All the observed features of radio galaxies are quite compatible with the predictions of the synchrotron theory.

Optical identifications provide our only sources of accurate distances for the radio galaxies. Largely enough the work of Matthews and Wyndham at the California Institute of Technology and Bolton and his co-workers at Parkes, we now have about 300 identified radio galaxies. Red-shifts have been measured for 62 of these—mainly by Minkowski, Schmidt, and Sandage. Fortunately, almost all the radio galaxies show emission lines, so that their red-shifts may be measured, even when they are quite faint.

The absolute magnitudes of the strong radio galaxies cluster very closely around $M_{pg} = -20.5$, so that the distance of an identified radio galaxy can be estimated with fair accuracy, even when its red-shift is not known. The dispersion in absolute luminosity is only $\pm 0\overset{m}{.}8$.

The radio galaxies are thus among the most luminous of all known galaxies. Presumably, the processes that give rise to strong radio emission can take place only in the largest and most massive galaxies. These galaxies are fairly rare, and it may be that every such galaxy is a radio galaxy, at some time in its history. Schmidt has examined the relative abundance of radio galaxies among all galaxies of suitable luminosity and morphological type, and he concludes that a giant elliptical galaxy is probably a radio galaxy for one tenth of its lifetime, or 10^9 years. This lifetime, as a radio emitter, could be broken up into a number of outbursts of shorter duration; indeed, this would seem to be required by other estimates of the lifetime of individual radio sources.

Quasi-Stellar Radio Sources. The radio properties of these objects differ from those of the radio galaxies in several respects. However, they were initially distinguished as a separate class of objects, on the basis of their optical properties.

The spectra of the quasi-stellar sources are often curved, especially at the low-frequency end. This is usually explained as the effect of absorption within a small and dense radio source region. The absorption may be either free-free or synchrotron reabsorption. In the decimeter range, the spectra of quasi-stellar sources are generally flatter than those of radio galaxies.

A few objects, pointed out mainly by Dent and Haddock, have spectra that rise at centimeter wavelengths. These objects, and a few others with very flat spectra, show intensity variations at short wavelengths. The characteristic times of these variations range from a few years, at 10 to 20 cm, to a few weeks, at wavelengths of 2 cm or shorter. In the optical range, almost all quasi-stellar objects show intensity fluctuations, some with characteristic times of only a few days, according to Sandage and Oke. These variations undoubtedly mean that the source regions are very small.

In the past three years, the optical spectra of quasi-stellar objects have been investigated extensively, mainly by Schmidt, E. M. Burbidge, Lynds, and their co-workers. The continuum intensities and colors have been examined by Oke, Sandage, Kinman, and Wampler, while earlier photographic observations of the brightest sources have been compiled by Smith and Hoffleit. The defining characteristics of a quasi-stellar source are that it should be unresolved (starlike) optically and have a large uv excess. It seems likely that optical intensity variations are also a common property.

Almost all the quasi-stellar objects have strong emission lines in their optical spectra, and these show exceedingly large red-shifts.

A considerable controversy has arisen over the interpretation of these very large red-shifts. The red-shifts must be Doppler shifts; gravitational red-shifts are excluded, since identical red-shifts are found for emission and absorption lines in 3C 191 and for permitted and forbidden emission lines in several objects. These various lines must be formed in different regions, which would have to lie at different gravitational potentials; thus, they would have different red-shifts, unless the gravitational red-shift were negligible.

The conventional explanation for the large red-shifts is to assume that they are cosmological. Then, the distances of the objects are given by Hubble's Law (with some fairly major corrections for the various possible world models), and the distances

are very large: $\sim 10^9$ pc. These large distances require large luminosities, both radio and optical. The radio luminosities are $\sim 10^{45}$ ergs/sec, comparable with the strongest radio galaxies. The optical luminosities are 10 to 100 times greater than those of the most luminous known galaxies.

The alternate explanation is known as the local hypothesis, in which the quasi-stellar sources are nearby objects with very large radial velocities. These are supposed to have been ejected either by our own galaxy (Terrell) or by the nearest radio galaxy, Centaurus A (Hoyle and Burbidge). While disposing of the problems of luminosity present in the cosmological case, the local hypothesis requires an explanation of the mechanism by which nearby objects have been accelerated to relativistic speeds and are supplied with energy over times of at least 10^7 to 10^8 years. The absence of objects with blue-shifts is also difficult to explain, in the Hoyle and Burbidge version.

The Relation Between Radio Galaxies and Quasi-Stellar Sources. Such a relationship (if, indeed, one exists) is by no means clear. On the one hand, there are a number of similarities: (1) the maximum radio luminosities (on the cosmological hypothesis) are about the same; (2) the radio spectra would probably be identical, if absorption were not present in the quasi-stellar sources; (3) the resolved quasi-stellar sources are usually double, as are the radio galaxies; (4) the N galaxies have colors and optical spectra similar to the quasi-stellar objects.

On the other hand, radio galaxies commonly occur in clusters of galaxies, whereas quasi-stellar objects do not seem to be in clusters. Since (on the cosmological hypothesis, at least) quasi-stellar objects are 3 to 5 magnitudes brighter than the brightest galaxies, we could expect to detect other members of an associated cluster only for the nearest sources—say, those with red-shift less than 0.4. In none of the 8 to 10 such cases is there any evidence of an associated cluster of galaxies. In 3C 48, Sandage and Miller have pushed the detection limit to $m_V = 24$, or 8 magnitudes fainter than the quasi-stellar object.

A number of other individual objects should also be accommodated within the framework of any over-all theory. For instance, in 3C 47 we have a quasi-stellar object surrounded by a double radio source which resembles, in every respect, a radio galaxy. If the red-shift of 3C 47 is cosmological, the diameter of the source is about 250 kpc, resembling Hercules A. Another strange double

source is 3C 343, which has two components with nearly identical spectra and intensities. Their diameters are greater than 2 sec, yet they are separated by 1,700 sec. Both have curved spectra typical of quasi-stellar sources, and no plausible optical counterpart has been found.

Cosmic Background

The cosmic background emission is a completely new field of radio astronomy that has opened up within the last two years. Observations at centimeter and short decimeter wavelengths show an apparently isotropic background emission with a brightness temperature of about 3° K. This emission, which has the spectrum of a blackbody at that temperature, remains after contributions from the galactic background, unresolved discrete sources, and atmospheric emission have all be subtracted. Points on this blackbody spectrum have been measured at 21 cm, 7.4 cm, and 3.2 cm. At wavelengths of 30 cm or longer, the rising galactic background would mask the 3° K emission, while at wavelengths shorter than about 2 cm, atmospheric radiation would be too intense to permit earthbound measurements. A further point at 2.16-mm wavelength has been inferred from the excitation of interstellar CN absorption lines.

The explanation proposed by Peebles and Dicke for this background emission is that we are seeing red-shifted photons emitted from a primordial fireball out of which our universe expanded and condensed. A number of theoretical deductions follow from the assumption of a primordial fireball with initial conditions that are at least partially set by the present observations. The analyses so far predict that the universe should have higher abundances of deuterium and He^3 than are actually observed, but this field has been explored only in a preliminary way.

The advances in extragalactic astronomy in the past 3 years years have been exceedingly (at times, chaotically) swift. It is exciting to contemplate what the next 3 years may bring.

REMARKS

I. Kazes (France)

I should like to present some recent results concerning the structure and spectrum of some normal galaxies observed at Nançay with the large radio telescope.

For the moment, the observing wavelength is 21 cm where the half-power beamwidths are 4 min in right ascension and 22.5 min in declination for the declination range of -38° to $+20^{\circ}$.

The receiver used is the one Blum described this morning, but it is used as a continuum receiver, taking the sum of all 15 channels. The details of the antenna and the observing technique will be described later. In the first part of the observing program, priority has been given to galaxies of greatest radio intensity and those that have the largest dimension in right ascension.

Here we shall talk in particular of the spirals NGC 5236 and NGC 253, which have already been observed several times, lately at 408 MHz by Dr. Mills and his co-workers at Mongolo, in Australia.

The sum of 11 drifts of NGC 5236 is compared with the sum of 11 drifts of BGM 2058-28, both of which are nearly at the same declination. The antenna temperatures of NGC 5236 and BGM 2058-28 are 1.9° and 5.7° K, respectively. The comparison source BGM has an E-W extension of ≤ 20 seconds of arc and, thus, is a point source for our beam, while NGC 5236 is certainly not a point source and possesses structure.

The superposition of NGC 5236 and BGM widened in abscissa does not show any detail of structure, and we estimate the dimension in right ascension of NGC 5236, assuming a Gaussian distribution to be 10 min. This dimension is comparable to that given by optical astronomers. Again, the sum of 11 drifts of NGC 253 are compared with BGM, differing by 3° in declination. The antenna temperature of NGC 253 is 5.1° K. Here we have evidence of apparent structure; the shoulders are clearly seen—the curves cannot be superimposed.

Finally, we suggest a possible decomposition of NGC 253 into a narrow unresolved component and into an extended one, with respective antenna temperatures of 4.6° and 0.5° K. The right ascension dimension of the extended component, assuming a Gaussian distribution, can be estimated to some 20 minutes of arc, in good agreement with optical results. The spectra of these two spirals

are obtained with the use of recent data from other observers.

For NGC 5236, the spectral index is -0.6. The extended component of NGC 253 has a spectral index of -2. For the unresolved component, the spectrum is practically flat from 408 MHz to 1,420 MHz while, in the region of 3,000 to 5,000 MHz, the spectral index is -1.

For those who are interested, other results concerning NGC 741 to NGC 742, NGC 1068, NGC 3034, NGC 4374, NGC 6946, and NGC 7331 are available.

NEUTRAL HYDROGEN IN DISTANT GALAXIES OBSERVED WITH AN INTERFEROMETER

R. D Davies (U.K.)

Pencil-beam surveys of M 31 and M 33 with a 50-kHz bandwidth yield sufficient information about the velocity and neutral-hydrogen distribution to give a clear idea of the usefulness of interferometry in investigating more distant galaxies.

The distribution of the total hydrogen content across M 31 and M 33 shows two peaks—the projection of a ring with a diameter considerably less than the over-all size of the galaxies. As seen with a bandwidth of 50 kHz, the distribution may become one-sided, depending upon the relation of the frequency to the local standard of rest at the center of the galaxy. These variations of the brightness distribution must be expected in studies of more distant galaxies. The interferometer at Jodrell Bank use the Mark I and Mark II telescopes, which are spaced 2,000 λ apart at an azimuth of 132°. The interferometer is particularly well suited to observing sources in the declination range of +10° to +40°, since a wide range of projected base lines is obtained as the position angle changes through the day.

The galaxies chosen for the detailed study are NGC 3571 (δb) and NGC 2766 (Sc). Both have an optical diameter of 4 minutes of arc and a red-shift velocity of 2,700 km/sec. Partial analysis of NGC 3571 shows a clear signal of 0.25 fu in 5 channels, each with a 200-kHz bandwidth. If this is eventually proven to be hydrogen-line emission, and not continuum, the mass hydrogen in NGC 3571 is about 7×10^9 solar masses. The sensitivity of the system corresponds to about 1×10^9 solar masses of neutral hydrogen at this distance.

REMARKS

M. Ceccarelli

A brief account is given of trials in detecting some parameter that could be measured with radio astronomy techniques and that could have some cosmological meaning. There are essentially two types of such parameters: those that are essentially related to the geometry of the universe; and those that are, instead, related to the change of the physical properties of the average celestial object with time. It is clear that what we are essentially seeking to obtain is some average quantity that could be related to the average flux of a group of objects; that is, with a parameter that is certainly related with both distance and time. The only quantities that are known today to vary with S are, possibly, the Hubble constant (determination of the deceleration parameter, etc.) and the exponent of the log S/log N relation (from ≈ 1.7 in the 10:1 fu range to ≈ 1 in the <0.1 fu range).

For this region, we are trying to develop techniques to measure parameters such as the average nonrandomness (clustering) and the variation of the average spectral index for sources belonging to different flux intervals. These seem to be the only parameters that can possibly be measured for extremely distant objects. We are not yet in a position to rule out either of these two experimental possibilities as unfeasible. In any case, it seems clear that both these parameters—if ever they are measured—will require very sophisticated statistical analysis in order to be extracted out of the many biases that are present.

297 RADIO RADIATION FROM CLUSTERS OF GALAXIES

H. C. Ko

A systematic survey of clusters of galaxies has been made at 40, 21, and 10-cm wavelengths with the NRAO 300-ft and 140-ft reflectors. Most of the radiation from 92 clusters examined is dominated by one or two member galaxies in the cluster, and the contribution from the intergalactic medium is negligible at these wavelengths.

Nine nearest rich clusters of cD type were also observed, and eight of them were found to be radio sources.

The nearest clusters (Coma, Virgo, and Perseus) have been mapped and resolved into several discrete sources.

DISCUSSION

H. van der Laan: If, within clusters, magnetic fields exist that are rather weaker than those in the cluster's discrete radio sources, then the weak intergalactic nonthermal emission must be expected to have a much steeper spectrum than that of the discrete sources. Particles escaping from the discrete sources will have their critical frequencies lowered by a factor $B_{gal}/B_{intergal}$. The result is a spectrum shifted to the lower frequencies, bringing the steepened portion of the discrete source's spectrum into the lower part of the radio range. This steepening, due to radiation losses in discrete sources, is then seen only at short wavelengths. Therefore, it is at decameter wavelengths, if anywhere, that the ratio of cluster emission to discrete-source emission of cluster members may be expected to obtain an appreciable value.

Ko: The present observations indicate that the intergalactic contribution is negligible at wavelengths shorter than 40 cm.

I have compared my observation of the Coma cluster with those made by Dr. Erickson and Dr. Galt at the 15-m wavelength. The cluster appears to have larger angular extent at longer wavelengths, and the spectral index is unusually high—about -1.7.

Moffett: Fomalout and Rogstad have made an interferometric study of clusters at Owens Valley. Their results agree quite well with Ko's.

IDENTIFICATION OF RADIO GALAXIES AND QUASI-STELLAR OBJECTS

J. G. Bolton

The Parkes catalogs contain 2,000 sources. They were originally found in a 408-MHz survey and then positioned at 1,410 MHz

(14-min beam) and 2,650 MHz (7-min beam) to an accuracy of ± 1 minute of arc.

More accurate (transit) positions ± 12 sec have been obtained for 640 sources. Of these, 400 have been identified from the Palomar Sky Survey. Most homogeneous data is for 383 sources with $+20^\circ > \delta > -30^\circ$. These have transit positions to ± 12 sec, and two-color survey prints. Twenty-six percent of the sources are identified with quasi-stellar objects (qso) (60 percent of these are confirmed as certain qso by uv excess or red-shift or both; the rest have blue excess on the sky survey). Of the sources, 38 percent are radio galaxies.

The qso are found to have a higher proportion with flat spectra than the radio galaxies. The spectra for the unidentified sources are distributed very similarly to the radio galaxies (i.e., mainly steep spectra), suggesting that the majority of the unidentified sources are radio galaxies.

The conclusion is supported by scintillation observations of 200 of these sources. Fifty percent of the qso scintillate; 20 percent of the radio galaxies show this effect. Of the unidentified sources, 25 percent scintillate. This is consistent with their being more distant (and thus smaller) radio galaxies, but it is not consistant with their being more distant and qso.

The distribution of the optical magnitudes of the identified radio galaxies strongly reflects the effect of the plate limit of the sky survey. The distribution of the optical magnitudes of the qso cuts off at about 1^m above the plate limit. Thus, we can conclude that the identifications with qso are essentially complete in the present sample, qso between 19^m and the plate limit corresponding to radio sources fainter than the Parkes survey limit. These may also have flatter spectra and require a short-wavelength-finding survey. Log N-log S curves for the three groups are very different. There is a slope of -1.8 for the qso, -1.4 for the radio galaxies (being flatter for the smaller flux), and -2.4 for the unidentified sources, which agrees with the results of Véron and Longair. The flattening for the radio galaxies is consistent with the loss of fainter ones beyond the plate limit. If the unidentified sources are galaxies, they can be combined with them; the composite log N-log S curve has a slope of -1.85! It suggests that the qso and radio galaxies span much the same volume of space (at cosmological distances).

Hoyle and Burbidge have pointed out that there is no magnitude red-shift relationship for qso either for the optical magnitudes or the radio magnitudes at 178 MHz. This does not necessarily

vitiate a cosmological red-shift, but it may indicate a large dispersion in the relevant absolute luminosities. For the 100 qso discussed above, those with steep spectra show no magnitude red-shift relationship consistent with the 178-MHz results. However, the qso with flat spectra do show a magnitude - red-shift relationship. They tend to be of smaller angular size and appear to have a smaller range in intrinsic luminosity. A search for objects with very large red-shifts could be most successful among faint radio sources with flat spectra.

THE POLARIZATION OF CYGNUS A AND VIRGO A AT λ = 1.95 cm

P. P. Mezger, J. Schraml, and Z. Turlo

With the NRAO 140-ft telescope, the polarization of the strongest nonthermal radio sources was investigated, and the following results were obtained:

Source	Integrated (p)	Polarization (ϕ_p)
Cyg A	3.1 ± 0.9	0 ± 8°
Vir A	3.9 ± 0.4	58 ± 6°
NGC 1275	0.8 ± 0.5	139 ± 34°
3C 273	0.7 ± 0.3	150 ± 27°
Ori A	0.4 ± 0.1	133 ± 18°

Orion A was used to check the instrumental polarization. The observed polarization of NGC 1275 and 3C 273 can well be explained as instrumental effects.

In the case of Cygnus A, the two components are barely resolved with the 2 minutes of arc beam of the 140-ft telescope. By mapping the source and changing the position angle of the feed in steps of 30°, we were able to construct the ridge line along the straight line connecting the centers of the E-W component.

We adopted a model of Cyg A consisting of two Gaussian-shaped components with HPW's of 25 sec which are separated by 108 sec

along the position angle 109°. This model was convolved with the Gaussian main beam of the telescope, and the amplitude of the two model components were adjusted to fit the observed ridge lines best. In this way we obtained:

Component	Cyg A (%)	ϕ_p
East	5.2 ± 2.5	22 ± 6°
West	7.3 ± 1.0	165 ± 5°

Due to our separation procedure, the quoted errors do not include systematic errors, which are very difficult to estimate.

Our results do not fit Soboleva's "uniform field" model of the polarization of the two components [Astron. Zh. 43, 266 (1966) in Russian].

POLARIZATION AND VARIABILITY OF EXTRAGALACTIC RADIO SOURCES

J. M. Bologna, E. F. McClain, and R M. Sloanaker (U.S.A.)

Variability

Of the extragalactic sources, 135 were observed with the NRAO 300-ft telescope at the 25.5-cm wavelength between October 7 and December 13, 1965. About half were observed daily for the first month, and about half were observed daily for the second month. Seventeen sources were observed over the entire 2-month period. No short-term variations were observed for any source greater than the peak-to-peak scatter due to noise, which ranged from 5 to 12 percent for most sources.

Polarization

Measurements of 134 extragalactic sources at the 21.2-cm wavelength were analyzed for linear polarization. Other sources from the California Institute of Technology and Parkes surveys were added to increase the sample of sources to 213. The observed polarization is found to be a function of galactic latitude and longitude, indicating depolarization of the radiation by the galaxy. The polarization of 117 sources at galactic latitude greater than 30°

is taken as an indication of the intrinsic polarization of extragalactic sources.

Discussion

F. G. Smith: What was the statistical significance of the conclusion about galactic latitude dependence of polarization?

Mayer: The chi-square test shows less than a 6 percent probability obtaining the observed figure by random sampling.

TIME VARIATION OF SOURCES

Dent (U.S.A.)

Large variations have been observed in the 8-GHz and 16.3-GHz flux densities of the quasi-stellar sources 3C 273, 3C 279, 3C 345, and the Seyfert galaxy NGC 1275. Between 1962 and 1966, the rates of variation ranged from 10 to 30 percent per year. However, beginning in early 1966, sudden rapid increases of 50 to 60 percent per year were observed in 3C 273 and 3C 279, at both frequencies. The radio spectra of the variable components of all the above sources have low-frequency cutoffs near 3 to 8 GHz, characteristic of self-absorption, and are relatively flat above the absorption frequency.

Both the short time scale of the variations and the observed self-absorption frequency imply that the linear diameters of the variable components are less than a few light-years. Repeated and frequent outbursts must be present in these sources to account for the observed flux-density variations and to produce the large total energies present in the sources.

Discussion

Lovell: With respect to the simultaneous upturn in flux density mentioned by Dent, I should like to mention that, at Cambridge, Williams has completed spectra down to low frequencies, and they remain identical. Palmer has also found the diameters to be less than 0.1 second of arc, using the Malvern interferometer. This makes the separation more than 20,000 diameters. A search for other such objects would be important.

VARIABLE RADIO SOURCES

K. I. Kellerman (U.S.A.) and I. Pauliny-Toth (U.K.)

The detection of significant time variations in the flux density of some quasi-stellar sources (qss) and radio galaxies puts severe limitations on theories of the origin and evolution of these objects. The limited data now available suggest that the radio emission from discrete sources is the result of repeated injections of relativistic electrons into magnetic fields on time scales ranging from about 1 to 100 years for qss and Seyfert galaxies, and 10^6 to 10^8 years for radio galaxies. Each burst results in a dense cloud of relativistic electrons giving synchrotron radiation that is initally optically thick out to centimeter or even millimeter wavelengths, and which then becomes optically thin at successively longer wavelengths. To a first approximation, the flux density will increase with the third power of time in the region where the source is optically thick. Frequent observations at many wavelengths are necessary to test this model and to determine the parameters describing the form and rate of expansion.

Regardless of any specific model that we may wish to check, detailed observations of the intensity of variable sources should provide answers to the following questions:

1. What is the over-all pattern of the time variations, as a function of wavelength over the spectrum ? What is the relation, if any, in the variations in the radio, infrared, optical, and x-ray portions of the spectrum ?

2. What is the shortest time scale for the variations of radio and optical wavelengths ? Are the variations periodic or random, and do they consist of successive increases over some well-defined ambient level, or do they oscillate about this level ?

3. How do the polarization parameters change with time ?

4. Do the angular dimensions of the radio sources change with time ?

5. Are the observed variations independent from source to source, or is there some correlation indicating that the sources are not intrinsically variable, but that the variations occur in the interplanetary, interstellar, or intergallactic medium ?

It is hoped that all observers with adequate facilities, particularly at centimeter and millimeter wavelengths, will take every opportunity to monitor known variable sources. Several of these are sufficiently intense that very large antenna are not

required and useful observations can be made with modest instruments. In fact, since most of the larger radio telescopes are used for a variety of programs and have frequent changes of instrumentation, the most effective observations may be made with smaller instruments that can devote a major portion of their time to this work and that can keep a constant check at any one frequency.

A VARIABLE RADIO-SOURCE MODEL

H. van der Laan

It is important to develop models for varying synchrotron-radiation sources for two reasons, among others. First, to provide observers with curves with which to compare their data and to guide them, after a fashion, in the decisions as to the relevance of possible observations. Second, to give a frame of reference within which available data may be interpreted, in order to impose meaningful conditions on the event that gives rise to the varying radio source and to reduce the range of speculative possibilities with respect to that originating event. The model described is that of an expanding source in which the relativistic gas cools adiabatically, and the magnetic field is diluted while the total magnetic flux is preserved. It is initially optically thick to its own synchrotron radiation at all radio frequencies. The consequent evolution and spectral variations are caluclated and related to available data. It is concluded that current data are too scattered in time and frequency to test the model rigorously. The available data are, however, consistent with the adiabatically expanding, optically thick source model and show all the expected qualitative features.

Angular diameter and peculiar spectral data, with their implications within the synchrotron hypothesis, also suggest that high opacity and rapid expansion must be expected.

If sources turn out to conform to the model in their gross features but depart from predictions in detail, then such departures will provide valuable clues as to the additional structure present. Some of these clues would be continued particle injection; energy-dependent inverse-Compton losses; and drastic particle leaks in jet formation. Data that are homogeneous in time and frequency

are now required, especially at short wavelengths (20 to 1.0 cm). Since the observations are not repeatable, simultaneous observations at comparable frequencies are required to check the results of these difficult measurements.

ON X-RAY ASTRONOMY

Friedman (U.S.A.)

Surveys of x-ray astronomy have detected about 30 discrete sources. Only one, the Crab Nebula, has been positively identified with an optical and a radio source. A position accurate to about 1 minute of arc has recently been obtained for Sco XR-1, the brightest source, but all other positions are uncertain by about 1.5°. Within the uncertainy of positions (~ 1.5°), x-ray sources lie in the directions of Cas A, SN 1572, Cyg A, and M 87. Assuming the correctness of the galactic identifications, it appears that all the observed sources are within about 3 to 4 kpc and represent a small sample of the galaxy, which may contain as many as 1,000 sources comparable to the Crab Nebula. The estimated x-ray luminosity of the galaxy exceeds the radio luminosity by 1 to 2 orders of magnitude. A similar ratio of x-ray to radio luminosity is found for Cas A, SN 1572, Tau A, Cyg A, and M 87.

Discussion

Van der Laan: Would you have seen a second Scorpius source if one existed? What fraction of the sky has been covered?

Friedman: We have covered 70 percent of the sky. The next strongest source after Scorpius is five or six times weaker. An old nova is reported to lie in the direction of Scorpius of 100 or 200 pc.

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COMMISSION VI

RADIO WAVES AND CIRCUITS

CHAIRMAN: F. L. H. STUMPERS (Netherlands)

First Business Meeting

CHAIRMAN: F. L. H. STUMPERS

Chairman Stumpers stated that his chairman's technical report was completed and approved. Anyone with specific comments was asked to see him in the next day or two.

Nearly all proofs of the Delft Electromagnetic Theory Symposium record are completed. Copies will be sent free in several months to all who attended the symposium.

Regarding terms of reference for Commissions VI and VII, the feeling of the meeting was to leave things as they are and not redivide technical areas between the two commissions. The Chairman proposed, and the meeting accepted, three areas for Commission VI: information theory; circuit theory; and theory of electromagnetic waves. He recommended three areas for Commission VII: electron devices; electron physics; and quantum electronics.

URSI cosponsorship will be recommended to the Board for the following meetings:

1. The IEEE International Symposium on Information Theory, Athens, September 1967.
2. The Summer School on Circuit Theory, Prague, 1968.

Commission VI will recommend to the Board that a grant be authorized for the 1968 URSI Electromagnetic Wave Theory Symposium to be held in Streza in June 1968. It was suggested that both short and long presentations could be accepted with perhaps some short papers summarized verbally by an invited speaker so that a maximum number of persons could have papers accepted.

The Chairman asked for help on CCIR study questions. Both

the U.K. and U.S.A. delegations agreed to help. Professor Siegel (U.S.A.) suggested that copies of all former questions and answers be sent to the Commission Chairman and to CCIR.

The Commission agreed with the plan for the Commission VI vice-chairmen to succeed the chairman. Dr. Stumpers was nominated to continue as Chairman for 3 more years; at the end of this term, the 3-year terms, with succession, will start. Professor Barlow (U.K.) was elected first Vice-Chairman, to become Chairman in 1969. Professor Siegel and Dr. Siforov (U.S.S.R.) were elected to continue as Vice-Chairmen.

Elsevier has withdrawn from the contract to publish General Assembly Proceedings. The Board has appointed a committee to decide on a course of action.

COMMISSION VI / SESSION OF SEPTEMBER 6 (A.M.)

Diffraction and Scattering in Nonionized Media

CHAIRMAN: H. M. BARLOW

TWO-DIMENSIONAL ELECTROMAGNETIC WAVEFIELDS WITH THE AID OF A MOTION PICTURE

H. H. Meinke (Germany)

Professor Meinke, Director of the Institute for High-Frequency Techniques of the Technical University of Munich, gave a brief talk which served to introduce a motion picture prepared by his group at the Institute. The work was undertaken to provide a method for better understanding the details of the propagation of waves in the near field of antennas and scattering objects. Since the field lines and the directions of the Poynting vectors of the wave fields of interest are time dependent, a sequence of momentary pictures separated by short time-distance intervals is necessary for more complete information.

The work to date has been restricted to two-dimensional fields and to problems for which the boundaries have been transformed to parallel planes through the use of conformal transformations. An earlier survey of this work was presented at the URSI Symposium on Electromagnetic Theory and Antennas in Copenhagen, June 1962, and is contained in the proceedings of that symposium (Pergamon Press, 1963). A large-scale digital computer was used to evaluate the differential equations resulting from the conformal transformations. For each momentary picture used in the film, 520 numerical solutions of a system of 12 differential equations of the first order were required.

In seeking the most graphic description for a wave field—one that would give the most information on wave propagation—the following four methods of presenting the momentary pictures of the time-dependent two-dimensional fields were considered:

1. By presentation of electric- and magnetic-field lines.
2. By presenting the direction and length of the Poynting vectors.
3. By presenting the energy distribution.
4. By a combination of (2) and (3).

Use was made of each of these methods in the film, and it was Meinke's belief that the fourth method, where energy distribution and energy movement were presented simultaneously, was the most satisfactory.

Meinke showed a film which ran for about 35 minutes and which showed wave propagation in a nonuniform rectangular waveguide with obstacles in three forms:

1. An obstacle with a semicircular longitudinal section inside and adjacent to the wall.
2. An E-plane compensated corner.
3. An outward bump with a semicircular longitudinal section.

The film was very informative and it is certain to be a powerful educational device. One must see it to realize its full impact.

In a paper distributed at the meeting, Meinke described wave propagation and showed several figures for the three waveguide configurations listed above. For the sake of brevity, comments on the film were restricted to the third waveguide configuration, and only a few typical situations were mentioned. Results for several frequencies were shown, and a strong frequency-dependent behavior was found.

For each of several frequencies, the film showed the electric-field lines propagating to the right; then, a series of pictures showed the directions of the Poynting vectors and views of the energy distribution, which was indicated by the size and distribution of an array of circles. In many cases, the electric-field lines were also shown in the latter pictures.

When the bump-plus-waveguide height is $\lambda_g/2$, the field lines and the Poynting vector pictures show energy propagating into the bump and, after some reflection, a considerable amount of the energy is transmitted beyond the bump. At a lower frequency, resonance occurs and essentially all energy is reflected; the right side of the bump is free of waves, except for a higher order evanescent wave shown by a single longitudinal electric-field line. At much higher frequencies, the behavior is essentially according to geometrical optics, with little energy going into the bump.

One interesting phenomenon which was clearly evident in the film was the occurrence of rotating fields. Field lines of constant phase meet at a rotation center at which the amplitude is zero. The direction of rotation of the energy changed from clockwise to counterclockwise as the frequency increased from below to above the resonant frequency.

Meinke reported that the discovery of a similar rotating-energy field on the surface of a scimitar antenna had enabled them to develop an improved antenna design.

Discussion

Jordan (U.S.A.) commented that the film was a most fascinating demonstration of electric-field phenomena.

Hansen (U.S.A.) asked how many field points are computed across the guide.

Meinke said that, for the Poynting vector and the energy distribution, 6 points are used, while for the electric-field lines, 12 points are used.

Karbowiak (Australia) asked if one could separate traveling-wave from stored-wave energy by this method.

Meinke stated that he hopes to be able to show magnetic- and electric-field lines separately, thus helping to show the amount of stored energy.

Marcuvitz (U.S.A.) said that the electric fields in a circular cavity should show both rotating fields and stored energy.

Hansen asked about the core size of the computer, and Meinke said it was 20,000 words.

The question of a possible ambiguity in the interpretation of the use of the Poynting vector was raised by Bremmer (Netherlands), since only the integral of the Poynting vector is unique.

Meinke was asked if copies of the film could be purchased. He said that this was not practical at present. He hoped to be able to provide copies in 2 years when additional results were available and improved reproduction techniques had been worked out. He invited requests for future showings of the present film in other countries.

Barlow spoke of his interest in the possible use of this technique for solving problems associated with the propagation of energy around an H-plane curve in a circular waveguide. He also reported that they had made some simple three-color films showing propagation behavior.

DIFFRACTION AND SCATTERING—PRESENT STATUS AND SOME RECENT DEVELOPMENTS

J. B. Keller (U.S.A.)

Prof. Keller gave an extensive review of recent developments and presented a number of outstanding problems. First, he reviewed formulations of scalar-diffraction and scattering problems. After reviewing the Sommerfeld radiation condition (Magnus and Rellich) and its extension to inhomogeneous media (Miranker, Kato, Ikebe, and Agmon) alternative formulations without the radiation condition were presented. One was (Ladyzhenskaya, Povzner, and Odeh) the "limiting-absorption principle" employed by Russian workers and others for Schrödinger's equations. This, in essence, assumes a small imaginary part for the wavenumber and, after solving the problem, one takes the limit as Im (K)→0. The other is the "limiting-amplitude principle" which recognizes that there is no pure time-harmonic problem, that all wave phenomena must be treated as initial-value problems, and that the time-harmonic solution is the limiting case of the "amplitude" of exp(-iωt) term. It has been shown that these principles are equivalent when obstacles are not present. Recent investigators (Buchal, Moraweitz, Lax, and Phillips) are testing the principles with obstacles present and have proved that the transient does decay. Also, the latter three workers have almost proved that the limited-amplitude proof is adequate.

Next, Keller reviewed the "scattering operator" approach introduced by physicists for the scattering of elementary particles. The scattering operator S, as employed by physicists, is defined by:

$$[\Delta + E - V(r)]\, u = o;$$

$$u = u_{inc} + u_{scat} \text{ and } u_{scat} = f\,(\theta,\phi)\, \frac{e^{ikr}}{r}\,;$$

$$\text{and} \quad f\,(\theta,\phi) = S\, u_{inc}$$

There are two problems. One is the "direct problem," which is to find S, knowing the potential function V(r). The other is the "inverse problem," which is to find V(r) by measuring f. Most electromagnetic studies have involved the direct problems, but the inverse problems have become more important in recent years. Good progress has been made on the inverse problem in recent atomic physics studies, and these results may be helpful for the electromagnetic problems (Gelfand and Levitan, Kohn

and Jost, Kay and Moses, a review article by Faddeyev, and a book by Argonovich and Marcenko). It is assumed that the objects are such that the scattering is governed by geometric optics and that bistatic radar cross-section data are available. The bistatic radar cross-section data are those obtained when, with a fixed-source location, the scattered data are measured in all directions. From these data, one can determine the Gaussian curvature as a function of the direction of the normal to the body, where the normal is the bisector of the angle between the source and the receiver.

It was hoped that one could determine the shape of the body from the Gaussian curvature of the object. It was shown, however, (Minkowski) that one must know the Gaussian curvature over the whole body. For this, a second illuminating source on the opposite side of the body is required. Even then, it is not easy to uniquely determine the shape of the object since this requires the solutions of difficult nonlinear partial-differential equations. Keller reported that he had obtained results for special cases, such as two-dimensional problems. Here, a single source is sufficient as it is, also, for obstacles with axial symmetry. When monostatic radar cross-section data are available for all points on the body, one can determine the body shape (Lewis and Keller).

Keller stated that it would be better to use the Kirchhoff method than the geometrical-optics method but, for this, both phase and amplitude radar cross-section data would be required. This problem corresponds to the quantum mechanical scattering problems; here, the requirement for phase data is obviated by working with many different frequencies. Much work is yet to be done on these problems.

Gabor worked on another inverse problem, and he invented the holography technique for solving the problems. With this technique, it is possible to reconstruct the scattered wave from the hologram plate containing the total information on the three-dimensional
315 object. It was noted that there had been considerable recent progress in holography due to the availability of coherent light sources.

Prof. Keller next reviewed the Watson-transform technique. Although it is widely used, the validity of this technique was not proved until five years ago (E. Pflumm and D. Cohen). The residue series converges outside the sector containing the source, but it diverges within this sector. An approach to obtain the residue series by a shortcut method, without going through the Watson transform, was reviewed. Sommerfeld, Pflumm, and Cohen

showed that the shortcut method works for some cases, but they found many functions that are not complete. The mathematical justification for the completeness is still an open question. This technique has been rediscovered by the physicists and applied to quantum mechanics by Regge. The complex poles for these residue series are called "Regge," "Sommerfeld," or "Watson" poles. An extensive study on the location of poles ("polology") and where they go as ka is varied has been made in recent years (Magnus and Kotin, Rubinow, Keller, and Goldstein).

Prof. Keller went next to numerical solutions. Numerical solutions for diffraction and scattering problems are obtained by first formulating the problem as integral equations for the surface currents (Mei and Van Bladel, and Andreason). However, the ability to solve these problems is limited by the size of available computers. It is possible to obtain solutions for objects if they are a few wavelengths in size or if an object has some symmetry, such as axial symmetry. For large objects, asymptotic solutions are more useful.

Discussion

Siegel: Professor Keller's paper applies to perfectly conducting objects; imperfectly conducting objects would lead to more complex problems.

Felsen (U.S.A.): If the object has corners, additional conditions are needed. For anisotropic media, "outgoing-energy condition" should replace "outgoing-phase condition." The case of the boundary extending to infinity and the Soviet work on the acoustic absorbing strip were discussed.

There was further discussion by Bremmer on the Watson transform and on the alternative, Green's function approach, used by Marcuvitz and Felsen. The problem of completeness [Tai (U.S.A.) and Felsen] and the use of phase information (Tai) were discussed. Senior (U.S.A.) gave an account of work at the University of Michigan on phase measurement and on the computations of zeroes of Legendre functions for a semi-infinite cone. The "limiting-amplitude-principle" was further discussed by Hansen.

Sinclair (Canada) reported that they had obtained improved analytical expressions for the current on the rectangular-cylinder problem of Mei and Van Bladel. He also reported that, by starting with a notched cylinder, they had obtained a numerical solution to the ribbon problem that agrees with accepted results and that

they had also obtained a solution to the ribbon problem for ka values to 15 or 20 by starting with a dihedral corner reflector. The possible use of analog computers for the solution of scattering problems was suggested by Karbowiak. Model measurements, radar and optical, are one form of the analog computer method (Siegel and Hansen).

Coding, Modulation, and Signal Processing

CHAIRMAN: F. L. H. STUMPERS

The session opened with the presentation of a survey report by Dr. V. I. Siforov and Dr. B. S. Tsybakov (U.S.S.R.) covering the significant contributions made to information theory—principally in the Soviet Union and the United States—during the period 1963 to 1966.

DEVELOPMENT OF INFORMATION THEORY, CODING, AND ADAPTIVE COMMUNICATION SYSTEMS

V. I. Siforov (U.S.S.R.)

In the Soviet Union, the United States, and a number of other countries, the years 1963 to 1966 were marked by considerable advances in the development of both the general information theory and its separate fields, such as: problems of the theory of data transmission, with allowance for quantum effects; theory of image transmission; theory of communication channels with random parameters; coding; and problems of the theory of adaptive communication systems. In the Soviet Union alone, several hundred work projects were carried out in this field. The present paper is devoted to a brief review of this work.

A considerable forward step in the field of fundamental definitions of the concept of quantity of information is the algorithmic approach suggested by A. N. Kolmogorov. The result of this approach is that the concept of quantity of information assumes

a more general nature and constitutes a further development of the fundamental ideas suggested by G. Shannon.

There have been certain advances with regard to problems of the theory of multidimensional Gaussian message sources and the channel capacity of a vectorial Gaussian channel without memory. Interesting work in these fields was carried out by M. S. Pinsker and B. S. Tsybakov.

The problem of the determination of probability characteristics of overshoots of random processes attracted great attention. In this field, some advances were made, both with regard to precise and approximate results, and also in obtaining experimental data. This includes works by B. R. Levin, Y. A. Fomin, and V. I. Tikhonov.

Along with the mathematical aspects of the processes of creation and transmission of information, a number of studies were carried out to establish the effect of the physical nature of an electromagnetic field on data transmission. Works by D. S. Lebedev and L. B. Levitin determine the information characteristics of an electromagnetic communication channel on the basis of statistical thermodynamics.

Problems of the theory of image transmissions, as an important type of information transmission, were studied in many works which may be divided into three groups:

1. Determination of a quantitative criterion of image quality.
2. Investigation of the statistic properties of images.
3. Development of new methods of image transmission.

D. G. Lebedev and D. S. Lebedev have suggested and investigated a method based on discriminating, quantizing, and transmitting only "contour" elements of an image. With this method, it is possible to obtain an image of satisfactory quality at five and, in the case of certain subjects, even at three quantization levels.

In recent years, in the Soviet Union, the United States, and other countries, extensive work has been done in the development of the theory of adaptive communication systems in which the method of information transmission and reception adapts to the varying parameters of the communication channel. In particular, L. F. Borodin and I. I. Grushko investigated methods for controlling the varying parameters of the communication channel and, depending on the results of the control, the procedure of the formation or processing of complex signals is altered.

Also interesting are studies in the field of the theory of

diversity reception in channels with fading. In the Soviet Union such studies were carried out by L. M. Fink and I. S. Andronov. In particular, note should be made of the work of I. S. Andronov on the optimum noise immunity of diversity reception.

In recent years, numerous studies were devoted to the theory of coding. This paper reviews only a part of these extensive studies. In particular, I. A. Ovseevich, M. S. Pinsker, and B. S. Tsybakov studied linear coding of stationary continuous messages for transmission through a continuous channel. V. D. Kolesnik and E. T. Mironchikov gave algorithms for constructing arithmetic codes for packet-error correction. They also analyzed majority decoding of cyclic and continuous codes.

Lately, many models of channels for transmission of digital information have been suggested. So far, however, the task of finding an adequate model of such channels has not been successful. Considerable efforts are still needed in this field, particularly in the experimental investigation of actual communications channels, in order to establish how far they agree with the accepted models. This problem and, also, a review of the methods for simplifying decoders for cyclic codes, are the subjects of a study by S. I. Samoilenko.

Despite the considerable progress made in recent years in the information theory, coding, and adaptive communication systems, many problems and tasks have not been solved as yet. A difficult problem in this field is that of finding effective methods for information transmission through multipath channels with random varying parameters; that is, methods that would make it possible to transmit information with high reliability and with speed closely approaching the optimum possible which, at the same time, would not be too complicated technically.

Discussion

The discussion commenced with a query from Stumpers concerning a paper by R. L. Dobrushin, "On the Recognition Decoding by the Wozencraft-Reiffen Method," Problems of Cybernetics, v. 12, 113-124, (1964). A brief comment on the significance of Dobrushin's conclusion to the effect that the Wozencraft-Reiffen algorithm entails an exponential increase in the average number of decoding operations was made by A. V. Balakrishnan (U.S.A.).

J. Lochard (France) raised a question concerning a result obtained by V. I. Siforov in, "On the Maximum Information from

a Moving Source," Transactions of the U.S.S.R. Academy of Sciences, Technical Cybernetics, 4, 80-83 (1963). Siforov explained that he computed the general capacity for the case where the transmitter (operating at constant radiating power) moves vertically away from earth at constant velocity v. Under the assumption that the channel is operating under optimal conditions, he found that the channel capacity is inversely proportional to vl_0, where l_0 is the altitude of the transmitter.

A. V. Balakrishnan presented a survey report entitled "Coding, Modulation, and Signal Processing." His report focused on the current status of the problems of signal selection and adaptive-communication system design and emphasized recent contributions made in the United States.

The discussion commenced with a question from L. A. Zadeh (U.S.A.) concerning the assumption that the signals S_i, i = 1, ..., M, are chosen with equal probabilities. Balakrishnan defended the assumption on the grounds that the designer has no *a priori* information concerning these probabilities and hence has no alternative but to assume that they are equal. Furthermore, the use of the signals in question with equal probabilities would maximize the rate of transmission of information.

Stumpers asked if the Digilock system described by Balakrishnan is likely to yield significantly better performance than the Orthomatch system developed at Lincoln Laboratories (Massachusetts Institute of Technology). In his response, Balakrishnan indicated that the two systems are difficult to compare and that the Digilock system is optimum when a number of signal components does not exceed M/Z. Continuing the discussion, Stumpers remarked that, at a recent meeting in Oslo where various modulation systems for space communication were analyzed, it was concluded that the differences between such systems as delta modulation, PCM, Digilock, FM with feedback, etc., were not substantial. Stumpers also pointed out that the techniques described by Balakrishnan would not be suitable for the analysis of FM systems because of their nonlinearity.

Stumpers queried whether Balakrishnan's analysis takes into consideration the Doppler effect. Balakrishnan replied that, if the magnitude of the Doppler effect is known, it can be taken into consideration in the selection of optimum signals.

With regard to the definition of adaptive-communication systems, Stumpers raised the question of whether ARQ systems and the sequential-decoding schemes of Wozencraft would qualify as

adaptive systems. Balakrishnan indicated that this was largely a subjective matter, depending on one's point of view.

Siforov inquired whether the techniques described by Balakrishnan could be extended to multipath channels with randomly varying parameters. Balakrishnan replied that, in principle, this was possible.

Karbowiak questioned Balakrishnan's exclusion of pattern-recognition schemes from the class of adaptive systems. In response Balakrishnan stated that this was largely a matter of definition and that, if pattern recognition were interpreted in a broad sense, then every technique, whether adaptive or not, could be regarded as a special case of pattern recognition.

Antennas

CHAIRMAN: E. ROUBINE (France)

LARGE ANTENNAS AND ARRAYS

R. C. Hansen

Hansen's paper contained an extensive literature survey (79 references). It covered topics in theory and practice of large arrays and, to a minor extent, aperture antennas. Referring to the work of Denkmann et al., on a method of scanning large Cassegrain-fed paraboloids, Hansen noted that the scanning motion is unconventional and provides the advantage of a more stationary feed system. Some degradation of the antenna patterns available for tracking might be expected due to the asymmetric aspect of the reflector aperture during scanning. It was his opinion that the 120-ft paraboloid at Lincoln Laboratories has one of the best diameter-to-rms tolerance ratios for such reflectors, with an rms tolerance of 0.020 in. The bootlace or Ghent (England, RRE) antenna provides broad bandwidth, as well as wide-angle antenna lens action, when delay-line principles are used. In his treatment of antenna array theory, Hansen recognized several unsolved problems presently receiving considerable attention. He stated that antenna arrays are usually analyzed as if they were fed by constant voltage or constant current sources. More properly constant power sources should be assumed. He cited the effect of mutual coupling on the radiating-element pattern, and he maintained that the usual separation into array and element patterns is not generally valid. Modal representations of radiating fields near the antenna apertures, including surface-wave

modes, have been used successfuly to describe the influence of mutual coupling between elements on hypothetical infinite arrays as well as on finite-sized arrays. Surface waves may be supported by the lossy radiating aperture or by dielectric radomes or support structures.

Several results of array theory study were mentioned: Lo and Lee, using a computer to study exhaustively the effect of leaving elements out of an example 19λ array, showed that side lobe level with nonuniform spacing does not necessarily agree with intuition. The conclusion is that designs for given constraints should be computer tested first. Several examples were shown of hardware developed to scan arrays by phase shifters, with the newest innovation being solid-state binary scanning. Surprisingly good results are obtained with only a 3-bit code.

Adaptive antennas were briefly discussed. The Van Atta retrodirective array needs to be active to eliminate interference between scattered and reradiated energy. IF and RF phase-lock loops for this purpose were described. Time modulation to achieve side-lobe control has been tried. Kummer has shown that 38 dB side-lobe level is possible even with a uniformly illuminated array. Similarly, time modulation of the transfer function can be used to produce multiple beams.

Discussion

Dr. Toraldo di Francia (Italy) drew the attention of the delegates to advances in diffraction antennas represented, for example, by a stepped spherical surface with an appropriate feeding system which permits these antennas to operate at many frequencies and produce high gains patterns in different directions. See Applied Optics, Vol. 4 (Dec. 1965).

ANTENNAS IN INFORMATION PROCESSING SYSTEMS

P. A. Matthews (U.K.)

This paper restricted itself to five basic topics: (1) use of autocorrelation and matched-filter techniques for scanning arrays; (2) use of angular ambiguity functions as an aid to understanding performance of antennas over a wide bandwidth; (3) noise-

cancellation schemes; (4) multiplicative and other nonlinear arrays; and (5) consideration of the antenna as an optical-imaging device.

If a receiving antenna is described by a narrow-peaked angular autocorrelation function, even though the pattern itself may be quite different, scanning produces a signal whose time variation, after matched filtering, has the shape of the autocorrelation function, with time of peak giving the direction to the source.

The ambiguity function originally introduced by Woodward to describe range and velocity measurement for radar may be adapted for describing antenna pattern versus frequency. This can be especially useful in describing frequency-scanned arrays. The work of Urkowitz (U.S.A.) was referred to. Radiating elements of an antenna are connected with suitable weighting functions to a matrix of delay circuits. Antenna elements can be widely spaced, and theory is developed for broadband signals. He concluded that the angular information is enhanced by use of inversely tapered aperture distributions. He reported that workers are attacking the problem of antenna response to external noise received by antenna elements, and an approach by data processing to reduce the deleterious effects of noise appears possible, using cross correlation between signals received at different antenna terminals. He briefly outlined design processes for nonlinear or multiplicative-processing antennas, concluding that their response in a many-signal or many-radar-target situation caused difficulties, and that their performance, when noise levels were high, was often inferior.

Contributions by Young and Ksienski (U.S.A.) were cited with reference to representation of the antenna as a spatial frequency filter between object space and image space. The antenna can be characterized by a transfer function and, indeed, a probabilistic representation can be developed to predict entropy changes between object and image when parameters are analyzed statistically. For a radar system so analyzed, it appears that a uniform amplitude distribution is desirable for the transmitting antennas and an inverse or interferometer-like distribution wanted for the receiving antenna. He agreed with earlier speakers that the optimization of antenna performance for partially filled apertures had not been completely solved, but good insight into information-gathering capabilities of antennas is achieved by use of Fourier transforms of the autocorrelation of the aperture distribution. An adequate theory connecting the continuous radiation pattern and the discontinuous aperture distribution is also needed.

Discussion

Thompson (U.K.) remarked that the Arsac (France) distribution of discrete antenna apertures to achieve nearly uniform spatial-frequency response was an important although ad hoc solution to the final problems discussed by Matthews. A para-Arsac arrangement for 11 elements has been achieved. Sletten (U.S.A.) stated that a 4-element Arsac array composed of 4-ft reflectors was being constructed to operate at 2 mm and that a large 6-mc array, based on these principles, was planned. Restoration methods to enhance angular resolution provide additional benefits on distributed post-detection antenna diagrams of radio-astronomical sources. Bracewell (U.S.A.) remarked that a rule for extending the Arsac principle had been achieved. Ko (U.S.A.) asked if general procedures for data processing of partial coherent signals was available.

Mrs. N. Alexeeva (U.S.S.R.) described in some detail a new antenna pattern synthesis method applicable to both equally spaced and unequally distributed radiating elements. The antenna pattern in the $\zeta = (2\pi/\lambda)\sin\Theta$ coordinates is given by:

$$\Phi(\zeta) = \sum_{n=o}^{n} A_n(\Phi)\, e^{j\zeta d^n} + \sum_{i=1}^{i=m} \int I_i(Z) e^{j\zeta} dz.$$

Depending on the antenna patterns to be synthesized, a spectrum of plane waves is developed by recourse to generalized Fourier transform techniques yielding poles in the complex transform plane. By evaluating the residues and locations of these poles, the spacing d_n, coefficients A_n, and current distributions I_i, can be determined. The paper has not yet appeared in the literature.

C. T. Tai asked if this was not closely related with the z-transform approach. Lack of time prevented an adequate discussion of these points.

A final contribution from workers at Darmstadt, (Koch) was described for the design of paraboloid-reflector feeds with high efficiency. A planar primary feed consisting of a central waveguide and five concentric feed rings has been built to produce the $[J_1(x)]/x$ distribution needed for low spillover performance. Patterns showing rectangular-shaped patterns expected for the primary feed were shown. Performance of this feed in a paraboloid has yet to be tested.

Nonlinear Circuits

CHAIRMAN: L. ZADEH (U.S.A.)

A REPORT ON SOME RECENT RESULTS OF THE THEORY OF NONLINEAR SYSTEMS AND CIRCUITS

A. Blaquiere (France)

Prof. Blaquiere gave a comprehensive survey of the advance in nonlinear circuit theory during the past three years, noting many subjects and many contributors, but with only very brief technical descriptions. He emphasized particularly lumped systems (described by ordinary differential equations). However, he also mentioned briefly the analyses of distributed-parameter nonlinear circuits. In this connection, he noted particularly the work of Scott and Nagumo. The important practical problems concern both transmission lines with distributed nonlinearities and linear transmission lines periodically loaded with active devices, such as tunnel diodes and reactor diodes.

In connection with lumped systems, he noted the importance of determining the normal-form differential equation, $\dot{x} = f(x,t)$, of a general RLC network, in contrast to the implicit $g(x,\dot{x},t) = 0$. The problem is of great importance, because the conditions for the existence and uniqueness of solutions of the normal-form equation are known and because solutions can be obtained by computer. Great progress has been made here. For example, Desoer and Katzenelsen, Chua and Rohrer, and Stern have established sufficient conditions for the existence of a normal-form equation in familiar network terms.

The problem of absolute stability, first described by Lurie, has been essentially solved. It concerns stability of systems which contain a single nonlinearity of the type $\sigma f(\sigma) > 0$ for $\sigma \neq 0$. The frequency-domain stability criterion of V. M. Popov was given special importance, and various further extensions of Popov's work were referred to. (However, extensions using functional analysis were left for Sandberg's talk.) Work of Kalman based on Liapunov's method was also noted.

Other studies noted concern oscillations in systems with many degrees of freedom. They include geometrical interpretations and steady-state forced vibrations in connection with strongly nonlinear systems, synchronization of oscillators, and applications to biological systems.

There was a brief discussion describing function techniques applicable to studies of subharmonic and superharmonic oscillators and to feedback systems with noise excitations. Other studies concerning noise-excited nonlinear circuits were reported, including an application of the Fokker-Planck equation, and noise effects in such circuits as feedback stabilization of oscillator amplitude.

Tunnel diode circuits were mentioned briefly.

Discussion

Stumpers asked whether the theory of circuits with nonlinear capacities might conflict with the second law of thermodynamics. Blaquiere stated that the conflict is possible and that this is a question of correct model building.

Zadeh noted that model building and identification of parameters, touched on by Blaquiere, is probably of the greatest interest to URSI.

A SURVEY OF SOME RESULTS ON THE THEORY OF NON-LINEAR CIRCUITS

I. W. Sandberg (U.S.A.)

The primary purpose of this paper was to show how functional-analytic techniques are contributing extensively to an understanding of how nonlinear circuits and systems act on input signals to produce output signals. A number of different

applications were surveyed, involving various forms of signals and circuits. Typically, results consist of sufficient conditions (on subsystems and input signals) for output signal behavior of one sort or another. The sufficient conditions are frequently reasonable from a practical standpoint. Many of the applications permit distributed components which exclude, for example, the use of differential equations of finite order.

The application described first (and in most detail) concerns systems with a single feedback loop in which there is a tandem connection of a single instantaneous but, possibly, time-varying nonlinear subsystem and one or more time-invariant, linear subsystems with memory. If $\Psi(x,t)$ is the response of the nonlinear subsystem to x at its input, Ψ/x is to lie between finite bounds. The impulse response k(t) and transient $g_2(t)$ for arbitrary initial conditions, describing the (combined) linear subscircuits, are required to meet certain reasonable conditions concerning integrability. Under these assumptions, the system is shown to be stable if a frequency-disk condition is met by the transform $K(i\omega)$ of k(t) in the complex frequency plane. In fact, the conditions have been proved to be sufficient for stability in numerous different senses. For example, suppose input $g_1(t)$ is bounded and $\rightarrow 0$ at $t \rightarrow \infty$, or has finite energy, or is merely bounded. Then, corresponding outputs have the same properties, respectively. There are similar relations for asymptotically periodic signals when $\Psi(t)$ is time invariant.

Variations were then noted concerning multiloop feedback systems and time-invariant systems relating to Popov's result.

Applications of functional analysis to quite different circuits and systems were then discussed more briefly. In the steady-state analysis of circuits containing nonlinear or periodically varying resistors, infinite systems of equations in an infinite number of modulation products are frequently truncated and solved as finite sets of equations, under the tacit assumption that the true solution is approached as the number of equations approaches infinity. The assumption is not actually always justified. Sufficient conditions have been obtained and, also, bounds on truncation errors. Other applications were noted that concern the convergence of iteration processes, for example, for recovering compounded band-limited signals and for computing equilibrium conditions in nonlinear circuits. Sufficient conditions and bounds on errors have also been established for techniques that are commonly applied to systems with "almost-linear" components, but that are not justified under all conditions.

Other problems mentioned briefly included relations between "causality" and "passivity" in nonlinear networks and formulation of the so-called normal form.

Discussion

E. S. Kuh (U.S.A.) asked if the theory applied to frequency division and shifting. Sandberg referred to a section on nonlinear or time-varying capacitors included in his text but omitted in his talk.

H. Watanabe (Japan) asked whether the theory of normal-form equations of nonlinear circuits, per Desoer and Katzenelson, applies to nonlinear coupled components. It was noted that this is a still unsolved problem but some work has been done on it in Japan, for example.

F. Carassa (Italy) discussed the signal-to-noise ratio in a phase-lock circuit with a band-limited input signal plus white Gaussian noise. He compared deterioration of the signal-to-noise ratio near threshold due to (1) signal attenuation in the nonlinear element, (2) distortion noise, and (3) noise induced by losses of lock (usually phase jumps of $\pm 2\pi$).

K. Morita (Japan) discussed briefly a problem considered by Goto and his co-workers. It concerns a resistance transmission line periodically loaded by shunt impedances of second order which are, essentially, biased-tunnel diodes with known phase-plane characteristics. Theoretical results include the limit of frequencies which can be transmitted along the line.

Zadeh emphasized the importance of system-identification problems in connection with space exploration and with satellite communication and control. He proposed that a session be devoted to system identification in the next General Assembly. He illustrated the problem with a simplified example, the determination of parameter a in equation $\dot{x} = f(x,a)$ from a finite amount of not perfectly accurate data.

Satellite Communications

CHAIRMAN: V. SIFOROV

SOME CONSIDERATIONS ON THE PROBLEM OF SPACE COMMUNICATIONS

P. Cooley and L. J. Cutrona (U.S.A.)

Professor Cutrona presented a system description of the use of optical-digital coding and decoding techniques in space communications. Bit rates of 10^6 to 10^8 bits/sec were considered practical at interplanetary distances of up to 10^8 miles. Optical data produced over a 6-inch square by an f/4 diffraction-limited lens can be resolved currently into 6×10^8 elements with 6 to 8 bits per element which, if processed in times ranging from 5,000 to 50 sec, lead to these bit rates being feasible. It was concluded by a simple analysis that, to achieve these bit rates by wideband transmission over interplanetary distances, 45 W of transmitter power into an antenna with an aperture area of 74 ft^2 would be needed at 2×10^9 Hz for a receiver-noise temperature of 100°K. The frequency choice was determined from considerations of atmospheric absorption, Faraday rotation, and receiver-noise characteristics.

Two methods of optical coding were described. One is a dictionary type in which a table is constructed containing a unique digital sequence for every possible message to be transmitted. The construction of such a table might be mechanized by a flying spot scanner. Upon reception, the message would then be decoded by cross correlating it against every possible code word in the table and selecting the one with the highest cross-correlation as

being the most probable message sent. By using the long codes made possible by optical processing and by taking advantage of the results available in the theory of error-correcting codes, a table can be chosen that gives low probability of error upon decoding. The other coding method consists of matrix multiplication of the message m-bit "vector" by a standard matrix containing all n-possible messages of m bits each. In this case, the message would be decoded by multiplying the received coded message by the inverse of the standard matrix.

The primary advantage of optical coding derives from its inherently large capacity for handling data. For example, more than 1,000 message waveforms could be cross-correlated simultaneously, each with a time - bandwidth product of more than 1,000. As a consequence, much longer codes can be used than are practicable with other techniques. They are also relatively inexpensive and compact.

Discussion

Stumpers raised the question of whether optical equipment of this type is small enough for use in satellites. Cutrona replied that optical decoders are still fairly large but that they would be restricted, at present, to earth-based use in satellite-to-earth communications. Encoders, on the other hand, are sufficiently small for satellite-borne applications.

COMMUNICATION SATELLITES

J. P. Hagen (U.S.A.)

Professor Hagen summarized briefly the successes that have been achieved in the United States program on communication satellites—Echo 1 (1960), Telstar 1 and Relay 1 (1962), Telstar 2 and Syncom 2 (1963), and Echo 2 (1964)—and pointed out that these early experiments demonstrated the feasibility and economy of both passive and active satellites. He then described in some detail the objectives of a new series of NASA communication satellites called "Applications Technology Satellites" (ATS). Among the objectives of the planned ATS experiments are the following: ground-to-air communication, single-sideband

modulation techniques, despinning of antenna beams, gravity-gradient attitude stabilization, and development of station-keeping thrusters.

ATS-1 (A) is a nonsynchronous satellite, to be launched in mid-1967, which will be used to test gravity-gradient stabilization. It will be of cylindrical shape with solar cells on its cylindrical surface. The gravity-gradient stabilization will be by weights at the ends of booms 137 ft long. Telescopes for solar track stabilization will also be included. ATS-2 (B and C), to be launched in late 1966, is designed for synchronous equatorial orbit and is to be spin stabilized. The antenna is to be despun electronically by phase change of array elements. ATS-3 (D and E), to be launched in 1968, will also be synchronous. It will be larger than ATS-2 and will be stabilized by gravity gradient. Specific experiments for this satellite are not yet determined. Stabilization accuracy improvements planned for the ATS series are as follows: ATS-1 (1966), $\pm 2°$; ATS-3 (1968), $\pm 2°$ to $\pm 5°$; ATS-4 (1969), $\pm 1°$; ATS-5 (1973), $\pm 0.2°$; and ATS-6 (1977), $\pm 0.000001°$.

A number of applications for communication satellites are being planned by NASA. They include: air-to-ground communications, navigation of long-range aircraft; ship-to-shore communications; broadcasting (first, to network outlets; later, to community outlets; and, eventually, direct to homes); and interplanetary communication relay stations. But before such applications can be achieved, more work is needed to obtain greater primary power than is available from solar cells, greater rf power, and more antenna gain from stabilized expandable microwave antennas. There are also some potentially severe problems of destructive interference with other services. Means must be developed to prevent interfering beams from pointing at each other, and there are difficult problems of frequency allocation. Exclusive frequency assignments would be impractical, except at extremely high frequencies, so frequency sharing appears to be the only reasonable solution. It was suggested that URSI help CCIR in establishing technically feasible means for sharing frequencies with the ground-based services.

Professor Hagen concluded by suggesting cooperation between URSI and CCIR on the following unsolved problem areas:

1. Development of a best form of modulation for communication satellites.
2. Multiple access to single repeaters without waste of bandwidth.
3. Use of frequencies above 10 GHz.
4. Improvement of knowledge on propagation over the horizon.

Linear Circuits

SOME ADVANCES IN LINEAR-CIRCUIT THEORY

Sydney Darlington (U.S.A.)

PROGRESS IN CIRCUITS

J. O. Scanlan (U.K.)

The developments covered by these two papers are summarized below:

The formulation of network equations in terms of state variables has attracted wide interest in the past 3-year period. The Bashkow-Bryant formulation has been extended to include transformers. Digital computer solutions have been formulated in terms of state variables, offering advantages in computation time. In linear time-varying networks, for which necessary and sufficient conditions for stability are not yet known, but for which stability bounds have been established, the state-variable formulation offers significant promise. The possibility also exists that this formulation will lead to an important approach to finding equivalent networks. Identification of equivalent structures is central to many problems—transformless n-port synthesis, for instance.

Certain constrained problems, which are simple at first sight, are, in fact, still involved. The necessary conditions for the impedance functions of an n-port of resistors are still not known. (The 1960 report anticipated that these would surely be known by 1963.) The solution of this problem is important to the solution

of transformerless two- and three-element-kind networks since an RLC network may be viewed as a resistive n-port with inductors and capacitors connected to some of its ports.

Solution of the transformerless three-terminal RC network problem remains at the stage of conjecture and not of theorems. Three subclasses of problems are of interest. One is the identification of the conditions that must be fulfilled by the driving-point and transfer functions. Another is the identification of canonical-element configurations. Finally, there is the problem of synthesizing any realizable set of functions. At this point, no one of these subproblems is solved.

The impact of the digital computer on network design has been tremendous. The use of computers in the design of filters has increased, with programs with sufficient numerical accuracy available to advance from the prescribed attenuation characteristic to the network design. Iteration techniques have been developed to achieve optimum filter design. Programs are now available for the determination of trees without duplication; this is important in the analysis of networks. A detailed summary of the present state of the art appears in a review paper by Kuo and in a book by Kuo and Kaiser.

An important area of research in the past 3-year period has related to new techniques for broadband matching. An extended definition of the scattering matrices has been applied to the Fano-Youla problem for more complicated loads (active loads, for example) and networks with time-varying or nonlinear elements. A new theory circumvents the need for finding the Darlington equivalent of the load to be matched. Other contributions relate to improved understanding of gain - bandwidth restriction and related topics, such as delay - bandwidth relations for low-pass networks.

Another fruitful area of network research is the area of strategies for the synthesis of lossless distributed networks for use at microwave frequencies. These procedures involve connections of sections of transmission line—in cascade, for example. Realizations involve microwave forms of Brune C and D sections.

Distributed RC networks have received attention, motivated by microelectronic applications. Various types of lines have been analyzed, and synthesis procedures have been formulated for sections of line with different characteristics.

Mixed, lumped, and distributed networks have also been studied. The theory finds application in microwave networks and

also in the design of electrical and electomechanical filters, including quarter-wave sections of transmission line. Problems encountered have made evident the need to study n-variable positive real functions. Such functions arise in the driving-point impedance of mixed, lumped, and distributed networks in which two or more variables are needed.

COMMISSION VI / SESSION OF SEPTEMBER 13 (P.M.)

Electromagnetic Properties of Ionized Media I: Source-Free Solutions in Ionized Regions

CHAIRMAN: K. M. SIEGEL (U.S.A.)

THEORY OF SOURCE-FREE SOLUTIONS IN IONIZED REGIONS

K. Bochenek (Poland)

Selected work in the plasma area was reviewed, the subject matter being divided into linear and nonlinear problems and grouped according to the mathematical techniques adopted. For the linear problems, asymptotic techniques were emphasized, the review concentrating on the work, growing out of the geometrical theory of diffraction, done by Keller and his colleagues at New York University. Some of the investigations of dispersion relations for cold, hot, and two-component plasmas were referred to.

In the realm of nonlinear problems, the paper concentrated on the role played by shock waves, which can only arise spontaneously in nonlinear media. If dissipation is neglected, the shock wave has the form of a discontinuous solution which can be treated by the theory of distributions. For uniqueness, the condition of entropy increase is not sufficient, and the required condition here is the evolutionary one, i.e., that small perturbations of the solution produce small effects. If dissipation is introduced, smoothing occurs, and it can be shown that, as the dissipation tends to zero, the solutions tend to evolutionary shock waves. Two nonlinear effects, the thermal and "striction" effects occurring within the ionosphere, were briefly discussed.

SOURCE-FREE SOLUTIONS IN PLASMAS

N. Marcuvitz

Professor Marcuvitz began by emphasizing the complexity of wave problems in plasmas, the difficulty of obtaining completely acceptable field equations, and the consequent use of various types of simplifying models, ranging from the kinetic nonlinear regimes, to the fluid-dynamic linear regimes. A major purpose in his presentation was to describe a systematic approach to source-free solutions, an approach that stresses common features exhibited by any model falling into the category of a linear homogeneous system. The initial discussion was concerned with unbounded regions, boundaries being introduced subsequently as a complicating factor.

A source-free solution or mode exhibits two characteristics: structure and dispersion. A space-time dependent field in an unbounded homogeneous region can be expressed as a superposition of modal solutions having an exponential dependence on space and time: $\exp(i\vec{k} \times \vec{r} - i\omega t)$. The four parameters k_x, k_y, k_z, ω, with the first triplet representing the rectilinear components of the wave vector $\vec{k}$, are not independent but, in consequence of the dispersion relation, any one can be expressed in terms of the other three. This leads to two basically different, but alternative, representations of eigenfunctions:

$$(1)\quad \Psi_\alpha(\vec{k})\exp[i(\vec{k} \times \vec{r} - \omega_\alpha(k)t)];$$

and

$$(2)\quad \Psi\alpha(\vec{k}_t,\omega)\exp[i(\vec{k}_t \times \vec{p} - \omega t)]\exp[ik_\alpha(\vec{k}_t,\omega)z],$$

338 where $k_\alpha = k_z$ denotes the wave number in the z direction. Solution (1) prescribes the temporal frequency dependence in terms of the spatial frequencies $k_{x,y,z}$ and constitutes a 'guided wave' in time; whereas solution (2) represents a wave guided along the space coordinate z. Use of either description leads to alternative forms of eigenvalue problems and associated orthogonality conditions, and each set of nodes can be employed in the synthesis of source-excited fields. The resulting integral representations can be reduced by asymptotic techniques that utilize the dispersion diagram relevant to each formulation.

Several examples were cited for illustration: (1) a one-

component unbounded warm plasma in an external magnetic field, (2) a warm isotropic plasma half-space, and (3) a cold anisotropic plasma half-space. The complicated form of the dispersion relation was schematized in terms of electrical networks containing ideal coils, capacitors, and gyrators. The eigenfunctions then being determined by the network resonances. In (1) when there is no magnetic field, the modes separate into electromagnetic and electroacoustic species whereas, in the presence of an interface, surface waves may exist that are deducible either from the field equations or the network. Marcuvitz concluded by stating that the procedure presented by him can be employed in even more complicated cases.

Discussion

Dr. P. C. Clemmow (U.K.) and Dr. H. J. Schmitt (U.S.A.) raised questions about the choice of boundary condition at a plasma interface and the validity of the fluid-dynamical model, especially in regard to cyclotron harmonics. In reply, Professor Marcuvitz remarked that the boundary conditions are physically motivated and, for the wave operator in question, uniqueness theorems can be derived for a variety of mathematical models. He noted also that attempts to arrive at the boundary conditions by assumption of a diffuse boundary layer. Concerning the validity of the fluid dynamical model, he suggested that it may be possible to incorporate aspects deduced from kinetic considerations into a fluid dynamical description.

In a short contribution, Dr. A. V. Gurevich (U.S.S.R.) described work carried out by E. Tsedilina and himself on the motion and diffusion of an inhomogeneity placed in the background of an anisotropic ionosphere. When the inhomogeneity is weak and long-lived and when its size is large, compared with the mean free path of the particles, a dispersion equation can be derived which contains the velocity $\vec{v}_a$ of the inhomogeneity, as well as a diffusion coefficient D_a (based on ambipolar diffusion). Both $\vec{v}_a$ and D_a depend strongly on the angle between the wave vector $\vec{k}$ and the (earth's) magnetic field, thereby leading to different propagation speeds of the various Fourier components required to describe the inhomogeneity. Even in the special case $\vec{v}_a = O$ (pure smearing), the surfaces δN = constant, descriptive of the shape of the inhomogeneity, depart from that of a simple sphere or spheroid. Gurevich emphasized that, in contrast to the exponential decrease of δN

encountered in ordinary diffusion processes, the present mechanism leads to an algebraic variation.

Professors Siegel, Marcuvitz, and J. A. Fejer (U.S.A.) participated in a discussion of questions relating to the assumption of charge neutrality throughout the analysis and to the derivation of the dispersion equation.

A short contribution by Dr. Clemmow discussed the "cold" approximation in two-stream problems. In many problems, particularly those concerned with instabilities associated with plasma streams, it would be helpful to know when the complicated "hot" (kinetic theory) model, in which the thermal motions of the charged particles are taken into account, can be adequately approximated by the simpler cold model. The paper examined the validity of the cold model estimates of the instabilities in a two-stream problem with equal temperatures, longitudinal waves only, and no magnetic field, the criterion of reducibility being the asymptotic equivalence of the two models in the limit of zero temperature. If the stream velocities are U and u (the latter referring to the denser plasma), with $u \ll U \ll c$, approximate solutions for the hot model can be obtained in the vicinity of the Cerenkov and cyclotron (instability) points With space-time factor $\exp[i(\omega t - kx)]$, it is found that for real k (complex ω) the cold model estimate is a valid approximation if

$$1 \gg (1/2\nu)^{1/3} \gg 1/z_o ,$$

where ν is the ratio of the number of electrons in the rare stream to the number in the dense stream, and

$$z_o = U-u/(\sqrt{2kT/_m}) .$$

Analogous results were derived for the case of real ω (complex k), and some of the associated peculiarities discussed. Since the criteria for validlity are not necessarily identical in the two cases, it is advisable to consider each in turn.

In a further short contribution elaborating on some points raised in Dr. Bochenek's paper, Dr. Gurevich discussed nonlinear effects encountered in radio wave propagation in the ionosphere. He was concerned particularly with the heating of electrons in the F region by a high-intensity electromagnetic beam, leading to the creation of a hole in the electron-density profile. Perturbations in the electron-density profile as a function of frequency were indicated. The changed electron distribution may give rise to focusing effects analogous to those encountered in nonlinear optics.

Dr. Gurevich emphasized the difficulties associated with continued heating of the electrons due to continued absorption of the impinging wave. He also described hysteresis effects which lead to double values of electron density and temperature as functions of field strength. He concluded by saying that such work in the Soviet Union is going on in the area of wave coupling, splitting, and scattering due to nonlinearities.

Electromagnetic Properties of Ionized Media II: Radiation and Scattering in Ionized Regions

CHAIRMAN: W. E. GORDON (U.S.A.)

RADIATION AND SCATTERING IN BOUNDED PLASMAS

Leopold B. Felsen

Professor Felsen reviewed analytical techniques useful in the study of plasma-like media. He pointed out that it is necessary to idealize the description of the medium and of the boundary conditions and that this constitutes a major defect when an attempt is made to apply the theory to practical problems. He emphasized, however, that the use of idealized models is worth while to provide new insight into the radiating and scattering processes.

After describing the media under consideration, which included anisotropic cold plasmas and isotropic warm plasmas, he discussed the dispersion relation, its representation by means of a wave-vector surface, locus of the wave vector $\vec{k}$ for a given frequency ω, and its relation to the group velocity and to the Poynting vector. An alternative representation, where one component of the wave vector is expressed in terms of the two others and of the frequency, can also be used and is well adapted to problems in layered media.

For a time-harmonic source, the field can be expressed through a Fourier transformation which in general cannot be evaluated exactly.

A most useful technique for obtaining an asymptotic evaluation of the far field is that of saddle-point integration. Only a finite number of plane waves contribute to the representation of the field, and those are easily obtained.

A ray-optical interpretation of the result in terms of incident,

reflected and refracted rays can be given. This was illustrated by a number of problems involving two media separated by a plane interface and an anisotropic unbounded medium.

A particular problem arises when the wave-vector surface extends to infinity: the power radiated by a point source may become infinite. This so called infinite catastrophe points out the unphysical nature of the model but can also be removed by considering only sufficiently "smooth" sources.

Felsen then discussed the problem of scattering by a conducting half plane in a compressible plasma and in a cold anisotropic plasma. The ray analysis again proves very useful. The diffraction patterns are strongly distorted by the anisotropy.

In conclusion, Felsen restated the importance of the refractive index surface and enumerated problems that still require attention.

These were: (1) the problem of coupling between optical and acoustic waves at a diffuse boundary; (2) the problem of guided waves (surface, lateral, leaky) at such a boundary; (3) the refraction at a plane interface for an oblique dc magnetic field; (4) the determination of current distribution on antennas; (5) the extension of asymptotic method to transition regions and to multipole expansions; (6) the transient problems of pulse propagation and radiation from moving charges; and, finally (7) nonlinear, random, and turbulent effects.

SOURCES IN UNBOUNDED PLASMAS

M. P. Bachynski (Canada)

Dr. Bachynski presented a review of underlying physical and experimental problems. He pointed out the importance of a consideration of real situations in view of the idealizations involved in the theory.

The first topic was the formulation of the boundary conditions for antennas in ionized media. The "normal sheath" surrounding an antenna without rf field has been approached in various ways: (1) the sheath is neglected; (2) it is treated as a layer of dielectric; (3) in warm plasmas, the "rigidity" condition is applied, i.e., the normal component of the electron velocity must vanish; (4) the "absorptive" boundary condition (which assumes that electrons striking the boundary are absorbed) is used for biased sources;

(5) a "hybrid" condition is used that involves the transport of electrons due to a space-charge field in the sheath and the thermal properties of the electrons.

A parallel review was next given to the sheath when an rf voltage was applied to the antenna. At low frequencies, pulsations in the normal sheath occur; at higher frequencies, there is a redistribution of the charges in the plasma. When the antenna is in motion—as on a satellite—a so-called ram sheath occurs, due to the sweeping out of ions in the path. When the moving antenna is very long, its motion through the earth's magnetic field develops a potential gradient along the antenna that causes a redistribution of the particle-collecting regions. The resulting sheath is known as the V × B sheath. It was pointed out that the valid application of these several conditions to actual antennas is not obvious.

The second topic treated was antennas in plasmas. The actual problem involves a boundary condition on the antenna, a current distribution in it, and the physical properties of the plasma. The analytical solution requires a highly idealized model. Among the models available are those that involve: (1) isotropic or anisotropic plasmas with the associated one or two transverse waves; (2) cold or warm plasmas that involve only electromagnetic or both electromagnetic and elecroacoustic waves; (3) one-, two-, or three-component fluid models with the associated electroacoustic modes. The problem is complicated by coupling between the modes. In a discussion of the electric dipole, it was pointed out that much attention has been directed to the determination of the radiation resistance and far field with the antenna immersed in these variously idealized media. Brief reference was made to the short antenna, the cylindrical antenna, the magnetic-line source, slots, and open waveguides.

Experiments on antennas in plasmas have made use of artificial dielectrics and gaseous plasmas. The former simulate regions with $k<1$ quite well but take no account of a sheath. The latter are complicated by the need to know the properties of the plasma.

A brief discussion of nonlinear phenomena, including plasma heating, plasma breakdown, plasma resonances, simulated echoes, and noncollisional dissipation of energy, was given.

In conclusion, it was emphasized that future progress depends greatly on a better correlation of theory with experiment that has been achieved in the past. Experiments should be made that are susceptible to theoretical verification; theory should concern itself with physically realizable conditions.

Discussion (Antennas)

G. A. Deschamps (U.S.A.) gave an explicit formula for the far field of an arbitrary antenna imbedded in a general linear uniform medium, isotropic or anisotropic. The formula involves the modal plane waves of the medium and geometric properties of the wave-vector surface.

K. G. Budden (U.K.) described some paradoxical results obtained by considering fluctuations of the open-circuit voltage of an antenna in a compressible magnetic plasma (see Onde Electrique, 1609, December 1965) and concluded that the model must be physically unacceptable.

J. A. Fejer (U.S.A.) described admittance measurements in the ionosphere of an 11-cm sphere in the 0.1 to 3.0 MHz frequency range. A resonance was observed in the dc potential of the sphere at about $1/4\ (3\omega_c + \omega_L)$. Some resonant effects in the mutual admittance between the sphere and one of the rocket antennas were also observed.

Du Castel (France) presented the work of Graff regarding the current distribution and radiation pattern of an infinitely long thin cylindrical antenna.

Discussion (Resonances)

Chapman (Canada) presented experimentally observed plasma resonances at the plasma frequency, electron, and ion cyclotron frequencies, and upper and lower hybrid resonances. He pointed out that the generating mechanisms and the form of the oscillations of the plasma are not well understood. He presented observations made with the Alouette 2 satellite and invited members of Commission VI to initiate theoretical studies to help provide explanations.

T. E. Van Zandt (U.S.A.) commented on theoretical plasma resonances and their correlation with observed values.

J. A. Fejer briefly described theoretical work on topside-sounder resonances. Calculations of the excitation of a collisionless plasma by a pulsed point-dipole source were discussed, including the decay, and the phase and amplitude of the excited field.

D. T. Farley (U.S.A.) presented the first observations of the ion gyro-resonance in incoherent scattering from the ionosphere. A peak in the autocorrelation function of the scattered signal was observed at time delays of one, two, and three times the gyroperiod $2\pi m_i/eB$ of hydrogen.

Second Business Meeting

CHAIRMAN: F. L. H. STUMPERS

There was a discussion on the format of technical sessions. It was difficult to arrange invited speakers as the session organizers did not know who the delegates from the various countries would be. It was decided that, next time, the official delegate of Commission VI from each country would send the Chairman a list of his country's delegates.

New topics. Several items were discussed as possible topics for 1969. Professor Zadeh stated that there was somewhat of an overemphasis on circuit theory in Commission VI. He felt that Commission VI should emphasize subjects of more interest to Commissions I through V; for example, the use of large computers. The following new topics were agreed upon:

1. Nonlinear electromagnetic wave propagation.
2. Applications of computers to information theory, circuit theory, and electromagnetic theory.
3. Physical models and parameter estimation; for example, planetary - atmosphere modeling.

National delegates will be asked for their suggestions in about a year.

Hansen was appointed Technical Editor for Commission VI.

A vote of appreciation was extended to the Chairman for a job well done.

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N67-16009

COMMISSION VII

RADIO ELECTRONICS

CHAIRMAN: P.A. GRIVET (France)

Low-Noise Devices

CHAIRMAN: H. HEFFNER (U.S.A.)

LOW-NOISE PARAMETRIC AMPLIFIERS

M. Uenohara (U.S.A.)

The major progess made on the low-noise parametric amplifier technology during the past 3 years is in the following three areas: (1) development of maser-like, low-noise amplifiers; (2) development of broadband amplifiers; and (3) incorporation of closed-cycle refrigerators for cooling the amplifiers. These developments were briefly reviewed and eight recent models of low-noise amplifiers were described.

It is not diffucult to build the parametric amplifier with the noise temperature higher than 20° K and with high reliability. However, it is still difficult to achieve a broadband amplifier with noise temperature lower than 20° K (especially below 10° K). To achieve an extremely low-noise amplifier with noise temperature lower than 10° K, further development of existent technology is needed. On the other hand, the amplifier cooled by a compact, closed-cycle refrigerator is reliable, economical, and of sufficiently low noise for most high-sensitivity receiver applications.

Prof. F. Carassa (Italy) reported briefly on the present status of low-noise parametric amplifiers in Italy. A 4-GHz receiver, with a cooled parametric amplifier as the first stage and a tunnel diode amplifier as the second stage, provide an over-all system noise temperature of 22° K with a bandwidth of 200 MHz. The parametric amplifier is pumped at 21.5 GHz and cooled at 18° K by a cryodyne refrigerator. A newer model provides 15° K-noise temperature and 500-MHz bandwidth.

LOW-NOISE AMPLIFIERS IN RADIO ASTRONOMY

B. J. Robinson (Australia)

The attainment of very low-noise, stable, broadband amplification is a permanent objective for the radio astronomer. However, a selection of amplifiers for a particular installation is often limited by economic considerations and by performances of other components, such as the antenna and switches. Performance characteristics of 19 operational radiometers from all over the world were reviewed for different types of preamplifiers—the maser, the varactor parametric amplifier (uncooled and cooled), the electron-beam parametric amplifier, the tunnel-diode amplifier, and the traveling-wave tube.

Their figures of merit, $T_n/\sqrt{B}$, were compared with each other for the present systems, as well as for future possible systems. The parametric amplifiers used in the present systems are far from the available optimum, and the parametric amplifier cooled at 20° K is expected to be the best, in figure of merit, over the entire microwave frequency range.

QUANTUM NOISE

H. Heffner

Prof. Heffner treated the problem of quantum noise in linear amplifiers, remarking, first, that the usual performance measure of noise temperature may be misleading. What is really required is the expression for channel capacity—how much the information-carrying capacity of the channel is degraded by quantum effects. He pointed out that this problem is intimately tied up with measurement theory in quantum mechanics, particularly the theory of repeated simultaneous measurements of noncommuting observables.

Heffner then gave the results of an analysis by C. Y. She and himself which culminated in an expression for the channel capacity of an ideal channel consisting of a transmitting antenna and a distant lossless cavity, the receiver in which the measurements are made. The resulting expression for channel capacity was in the familiar form of

$$C = W \log [1 + S/N]$$

where W is the modulation bandwidth, S the signal energy received in a time $t = 1/W$, and N is the noise energy given by

$$N = \hbar W [n_{th} + 1]$$

where n_{th} is the number of thermal noise photons appropriate to a free-space temperature T. When T approaches zero, the quantum noise is simply $N = \hbar W$.

If the receiver includes an ideal maser (one that is lossless and that has a complete population inversion), the channel capacity is not degraded.

Nonlinear Optics and Laser Radar

CHAIRMAN: R. J. COLLINS (U.S.A.)

The session covered a variety of topics in advanced electro-optic technology in five papers.

The first paper was on nonlinear optics and optical-frequency conversion by R. V. Khoklov (U.S.S.R.) of the University of Moscow. J. G. Atwood (U.S.A.) of the Perkin-Elmer Corporation then spoke on several laser radar systems that are analogs of microwave technology. W. T. Peria (U.S.A.) of the University of Minnesota, discussed the prospect of improving the red response of photoelectric detectors from the point of view of basic understanding of the photoemissive surface. A. Orszag of the École Polytechnique, Paris, spoke about the joint project at the École Polytechnique, and the Pic du Midi Observatory to study the moon by laser optical radar. Sh. Saito (Japan), of the University of Tokyo, spoke about the use of a laser system to measure currents in very high voltage transmission lines. He also described the activities at the Kagoshima Space Center of the University of Tokyo in preparing a ground station to operate with the Miros satellite of the United States.

NONLINEAR OPTICS AND OPTICAL-FREQUENCY CONVERSION

R. V. Khoklov

Khoklov began by reviewing the historical development of nonlinear optics and basic nonlinear effects that can be used for frequency

multiplication in the optical range. He described the nonlinear polarizability of the materials used and the phase-velocity matching of interacting beams. The factors that limit the efficiency of the conversion process were also discussed. The latter include the limited cross sections of the beams and diffraction effects that reduce the volume of the nonlinear material in which the traveling waves interact. Among the frequency conversions that have been carried out with high efficiency are the addition of the outputs of ruby and neodymium lasers to produce radiation at 0.42 μ. The third harmonic of a Nd^3 laser has been generated from 10 to 20 MW of input with an efficiency of 10 percent; 3 to 4 MW of the fourth harmonic at 0.26 μ have been obtained at 2 percent efficiency. Khoklov speculated that, with materials now known, the generation of 1 W (peak) of coherent radiation at 0.105 μ is possible. This would be obtained as the sixth harmonic of the ruby-laser output.

Use of the stimulated Raman effect to produce a wide range of visible and infrared frequencies was described. The limitation of the method for high-power conversion is the self-focusing effect, which leads to the breaking up of the pump beam into fine waveguide-like filaments. This effect is an instability in the propagation of intense beams whose field intensity is sufficient to increase the index of refraction of the medium through electrostriction, or the Kerr effect.

Khoklov then described the optical parametric converter. This device is a fully tunable optical-frequency converter that converts a pump beam at W_p into two beams at W_1 and W_2 so that $W_p = W_1 + W_2$. The first successful parametric converter, by Giordimaine and Miller, used lithium niobate, with the phase matching controlled by changing the temperature of the crystal. Khoklov also described a new converter, using potassium dihydrogen phosphate (KDP). The phase matching was tuned by mechanical rotation and electro-optic effect. This unit used the second harmonic, a Q-switched Nd^{3+} laser, also generated in KDP, as a pump. It had a threshold of 7 MW and an output of about 0.5 MW. It was tunable over the range of 1.20 μ to 0.95 μ. The method is intrinsically capable of tuning over about 0.4 μ to 1.0 μ.

In the future, Khoklov foresaw the application of lasers, frequency multipliers, and tunable converters to the generation of a tunable optical-frequency band over the entire spectral region, from ultraviolet to infrared.

As an application of the shortwave coherent radiation made available by these frequency-conversion techniques, the field of photochemistry was mentioned. It should be possible, for example,

to dissociate a particular ligand from a "molecular frame" by a proper choice of the quantum energy of the irradiation. There are also biological and medical applications.

Khoklov concluded by predicting that at the next URSI meeting there will be a special session on applications of nonlinear optics and frequency conversion, since progress in the field is now so rapid.

SOME LASER RADAR SYSTEMS THAT ARE ANALOGS OF MICROWAVE TECHNOLOGY

J. G. Atwood

Atwood discussed laser radar systems from the standpoint of determining which types are likely to be successful applications of lasers. Definition of successful was that the laser system should function better or be less expensive than competing microwave and incoherent optical systems. He cited a proposal to practice aerial photography by the hologram technique—which is the optical analog of synthetic aperture radar—as an example of an application that is unsuccessful with today's laser technology because it requires far too much average laser power and offers little advantage over conventional photography.

He cited the pulsed-ruby range finder as an ideal example of a successful application, because it conforms to certain general rules for successful laser applications. These include operation over a small solid angle, at a low information channel capacity, so as to require only low average radiated power. Successful laser systems should also exploit the narrow frequency band of lasers to suppress background and should not use the phase of the optical carrier or be used outdoors for applications that require operation in all weathers.

The quantum noise, when $h\nu >> kT$, is a reason for needing more received power in laser systems than the analogous microwave systems. He also pointed out the system difficulties characteristic of optical systems, in which the received field angle is much larger than the diffraction angle of the aperture. This makes predetection bandwidth filtering difficult, causing intensity detection systems to have the signal-to-noise ratio degraded by background radiation in daytime.

The degrading effects of pointing error and atmospheric turbulence on heterodyne detection systems were seen to rule them out when the receiver diameter must exceed 3 cm in daytime or 30 cm at night, except for the 10.6 μ CO_2 laser, when the transverse coherence diameter is 1 to 3 m.

Retroreflectors were shown to have 10^{10} more effective cross section for light than they do at microwave frequencies, thus placing them in a special relation to laser systems. A commercial geodetic distance-measuring instrument was described that uses a radio-frequency-modulated, continuous laser beam to measure a retroreflector to 3-mm accuracy.

Atwood described a similar proposed system for measuring angles as well as range to locate a retroreflector to about ±1 cm accuracy in 3 coordinates up to distances of 10 km. He showed a film of an experiment in which the influence of atmospheric turbulence on the fine pointing of the system was measured. While the results show that such precise three-dimensional tracking is indeed feasible, the complete system, designed for precision trajectory measurement on a rocket range, has never been installed, owing to competition from a cw microwave radar which, though less precise, operates in all weathers. This illustrates the real difficulty of applying lasers successfully in technology where better-than-required performance is of no value if it incurs any other disadvantages.

Atwood closed by speculating that, in scientific applications, the extra precision of laser and retroreflector systems will remain of value. He cited a proposed project to place a retroreflector on the moon, and measure the distance to it to 1-m accuracy, as a laser application from which would ensue much scientific value to the fields of geodesy, celestial mechanics, and cosmology.

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IMPROVEMENT OF THE RED RESPONSE OF PHOTOELECTRIC DETECTORS

W. T. Peria

Peria described a series of experiments on the influence of adsorbed Na atoms on a clean germanium surface. The detailed dependence of the work function on the amount of adsorbed sodium was described. Anomalous points in this curve were related to surface structural

developments revealed by changes in the low-energy electron diffraction pattern and in electron-reflectance spectra. Taken as a whole, the results lead to a detailed model of the surface and of the sites on which the adsorption occurs. It was suggested that surface technology has achieved sufficient control over the specimens with which it must deal to enable one now to begin to apply detailed theoretical analysis. Such procedures have not been profitable in the past because of inadequate knowledge of surface structure. One of the expected results of a combined theoretical - experimental approach to the study of semiconductor surfaces is the achievement of lower work functions than were previously attainable. Such surfaces would have improved photoelectric response in the red end of the spectrum.

MOON STUDY BY LASER OPTICAL RADAR

A. Orszag

Orszag reviewed the technical problems of studying the moon's surface by optical radar, using incoherent scattering and the scientific information that could be gained by this study.

If no retroreflector is used, the experiment requires at least a 10-J Q-switched ruby-laser pulse to obtain a range precision of 10 to 50 m. Damage to the transmitter telescope optics is a problem with such a laser beam.

The size of the receiver telescope and the number of pulses that can be correlated determine the field angle that can be accepted. Background noise will limit the measurement for large field angles, and diffraction and atmospheric effects will preclude small angles. One solution requires a $10m^2$ receiver area and 30 pulses, permitting a field angle of 50 arc seconds to be illuminated.

The reflectivity of the moon averages 0.1, but is anomalously higher near 180° to the incident beam direction, reaching almost 0.3 within $\pm 1^\circ$ of the reverse direction. There is no data within this $\pm 1^\circ$ range. A laser experiment could provide it, as well as measurements of the optical depolarization effect of the surface material. Orszag noted that the rate of progress in laser power is slow enough to make detailed long-range planning of such a project feasible.

USE OF A LASER SYSTEM TO MEASURE CURRENTS IN VERY HIGH VOLTAGE TRANSMISSION LINES

Sh. Saito

Saito described the application of a cw neon laser to measure the current in a very high voltage power-transmission line. A bar of glass is placed near the line. The magnetic field of the current in the line causes circular birefringence in the glass, via the Faraday effect. This is measured continuously, from a remote location, by its effect on the polarization of a laser beam, which passes through the glass bar. The system has outstanding advantages over the current transformer, with which it competes. These advantages are: no very high voltage insulation problems; eventual lower cost; and rapid speed of response, permitting instantaneous response to lightning surges, for example.

Saito also described the work at the University of Tokyo Space Center in building and testing a ground station for the United States Miros modulated-retroreflector satellite project. The ground station has a cw neon-laser transmitter and a microwave receiver. The testing unit, located at a distance, has a microwave transmitter with several attenuators and frequencies which can be switched in by a remote optical or microwave command signal. The status of this transmitter is encoded as an "answer-back" signal and sent to an optical modulated retroreflector. The answer-back signal is impressed on the retroreflected laser beam and picked up at the group station. The purpose of the testing station is to boresight and calibrate the microwave receiver of the Miros ground station.

On Continuous-Wave Lasers, Gas Lasers, and Holography

CHAIRMAN: J. G. LE MEZEC (FRANCE)

The third session of Commission VII was divided into two topics: (1) state-of-the-art in lasers, and (2) the applications of lasers to holography. In the section on lasers, three papers were presented and one read by title. Of these papers, two were from France, one from Germany, and one from the United States. Both papers on holography were from the United States.

The Chairman of the first portion was J. G. Le Mezec; for the second portion, M. Chodorow (U.S.A.) presided.

SECTION ON CONTINUOUS-WAVE LASERS AND GAS LASERS

1. On cw Solid-State Lasers by K. Gurs (Germany)
2. High Power Ion Lasers, by E. I. Gordon, BTL (U.S.A.)
3. Molecular Lasers, by G. Amat, Faculté de Science, Paris
4. Problem of Monomode Power Laser, by J. G. Le Mezec, CNET, Paris (paper submitted but not read, due to lack of time)

Developments in cw solid-state lasers were summarized by K. Gurs of Siemens Halske, with emphasis on the work at Siemens. A list of operating cw lasers was given. At this time, the Siemens group has attained room-temperature cw operation of a ruby laser in simple configuration. A mercury vapor lamp is used as a pumping source in a small, silver elliptical housing. With this configuration, an efficiency of ~0.04 percent and output of ~1 W has been achieved. Mode control has been demonstrated by both geometry

and temperature. In comparison with the ruby, recently YAG: Nb^{+++} has produced cw output powers of $\sim$100 W, with an efficiency of $\sim$3 percent. The continued work on ruby cw systems can be justified by the slope of the input-output curves. For YAG: Nd^{+++}, no increase in efficiency is indicated, while the efficiency of ruby is increasing rapidly with input power. The present extrapolation indicates that ruby may yet be useful for cw applications. Gurs estimated that an output of $\sim$200 W with $\sim$2 percent is possible.

Unfortunately, because of a shortage of time, the paper by Le Mezec was not presented. It was particularly unfortunate because his paper was to discuss a fundamental problem common to most scientific applications of laser—production of single modes. The abstract is reproduced below. One of the significant achievements is the 15 MW single-frequency 6328-Å He-Ne laser.

THE PROBLEM OF THE MONOMODE POWER LASER

J. Le Mezec

The Fabry-Perot resonators used in lasers operating in the visible and near infrared regions of the spectrum generally have several resonant frequencies in the emission line profile of the active material. It follows that the power increase in excitation enhancement is accompanied by the appearance of new modes and, thus, new frequencies in the spectrum of the emitted wave.

A monomode laser can be obtained by two simple methods: (1) either by a decrease in the gain of the tube or an increase in loss until a single resonant frequency is obtained in the region where the gain is higher than the loss; or (2) by shortening the length of the tube, which sometimes leads to considerable technological difficulties, especially when the line width is large (argon laser).

These two methods result in a severe reduction of the emitted power. Work has been carried out in other directions, to develop long lasers, operating with a gain very much higher than the oscillation level and able to give a high emission power on a single frequency. This can be achieved by replacing at least one mirror by an optical system having a reflection coefficient that is frequency dependent. A Fabry-Perot interferometer or a Michelson interferometer has been used in this manner. Another method proposed more recently consists of dividing the light beam into two parts

having orthogonal linear polarizations using birefringent elements inside the laser. In these devices, the resonant cavity consists of at least three mirrors and one or more optical separators. The elements of this cavity may be represented by matrices following classical methods in microwave studies. Resonant frequencies of complex systems can be computed in this way, and the operation characteristics of these systems, when used in a beam, can be determined. By these methods, a He-Ne laser was able to produce about 15-mW power on a single frequency near 6,328 Å. However, there are some mechanical stability problems, so that a servo-loop stabilization needs to be used.

The power produced on a single frequency may be higher than the power obtained on one mode from a similar laser in monomode operation. This can be explained by the theories of Lamb and Bennett (hole burning).

However, the increase in energy output of monomode gas lasers in unfortunately accompanied by the fact that only a small fraction of the active atoms of a gas laser contributes to the light emission on a given frequency, due to Doppler broadening of the line. Under ordinary conditions, active atoms provide only a small coupling between modes, but the use of a modulator inside the laser resonator allows a strong coupling by parametric transfer of energy between resonator modes. The spectral components emitted by the laser are no longer independent, but form a stable wave having a complex spectrum; for example, a frequency-modulated wave or a pulsed amplitude-modulated wave having a recurrence frequency equal to the modulation frequency.

Two methods have been proposed for the transformation of a frequency-modulated laser with the use of an internal modulator in a device producing a monochromatic wave: (1) either the addition of another frequency modulator that suppresses the emitted wave modulation; or (2) the filtering by a selective device that couples outside only one component of the frequency-modulated wave. Thanks to the internal modulator, a larger number of the active atoms may contribute to the radiation energy, i.e., all atoms whose transition frequency is shifted by the Doppler effect toward one of the spectral component frequencies of the frequency-modulated wave.

SECTION ON HOLOGRAPHY

RECENT ADVANCES IN HOLOGRAPHY

Emmett Leith (U.S.A.)

Dr. Leith showed the basic configurations used for making and displaying holograms. He also showed slides of a hologram and pictures of reconstructions made of several holograms. These reconstructions had a number of properties. Some were monochrome transmission-type holograms. In addition, reconstructions of color holograms were shown.

The effect of thick emulsions was discussed, and it was shown that both color selectivity and angle selectivity could be achieved by the use of such thick emulsions. He showed how the angular selectivity could be used to record several scenes on one hologram.

He continued with a number of possible applications of holography. Included among these were (1) vibration analysis, (2) distortion analysis, and (3) contour mapping. In the reconstructions in color, Dr. Leith showed that a reasonable white had been achieved. This is significant, inasmuch as color balance must be carefully adjusted.

He also discussed some work in noncoherent holography and pointed out the problem of contrast loss when complex scenes are used. He referred briefly to possible techniques for combating this property of noncoherent holograms.

SOME CONSIDERATIONS IN HOLOGRAPHY

Louis J. Cutrona (U.S.A.)

Dr. Cutrona discussed three main topics: (1) noncoherent holography, (2) the dynamic range of the reconstructed image in holography, and (3) a comparison of holographic imaging with ideal-imaging systems.

In noncoherent holography, the use of a triangular interferometer, as proposed by Cochran, was discussed. A reconstruction with the use of this scheme was shown. The problem of contrast loss and possible schemes for combating it were briefly touched upon.

The dynamic range in the reconstruction of a hologram was discussed. A derivation by Falconer was discussed. It was shown that reconstructed images have very large dynamic ranges, despite the fact that the hologram itself has a very low contrast.

An analysis of an ideal imaging system was made. This is defined as one that images planes perpendicular to an optic axis with constant transverse magnification into a conjugate plane, also perpendicular to the optic axis. It was shown that such a system obeys the classical thick-lens formulas.

In the holographic case, an analysis was made for the situation in which the reference signal and the reconstruction beam are both spherical. It was shown that, in general, distortion and aberrations arise. However, for proper locations of the reconstruction beam, these distortions and aberrations can be removed. Each point can be considered as obeying a lens formula with a focal length, depending on the location of both the reference beam and the reconstruction beam. It was shown that transverse magnification can be achieved by reconstructing with a wavelength different from the exposing wavelength. It was also shown that a change in scale factors affects the transverse magnification differently from the manner in which it affects the longitudinal magnification. By a proper choice of magnification of the hologram and the use of reconstruction wavelength, it is possible to get magnification without distortion.

The reconstruction of a color hologram was shown. This hologram was made with an argon laser for the blue and a helium-neon laser for the red. Despite the absence of yellow, a relatively good white was achieved in the reconstruction.

Microminiaturization

CHAIRMAN: JOHN C. LINVILL (U.S.A.)

REVIEW OF ADVANCES IN MICROELECTRONICS

John C. Linvill

The maturing of the technology of silicon monolithic integrated circuits is the dominant advance in microminiaturization during the period of 1963 to 1966. This technology relies upon photolithography for fine machining and utilizes alternate masking and etching of SiO_2. Dopants are introduced through windows cut in SiO_2. Commercial building blocks comprising tens of elements have achieved industrial importance in a surprisingly short time. The planar bipolar transistor is the standard active element of these integrated circuits. Silicon resistors and capacitors are the passive elements. Many circuits are produced on a single silicon slice, which is then cut into dice containing one circuit each. These small dice can be simply bonded to convenient headers. Thermocompression bonding serves to connect the silicon chips electrically to other parts of the circuit by means of fine gold wires.

A related technology employing metal-oxide-silicon field-effect transistors (MOS transistors) has recently emerged. MOS integrated circuits have different properties from the silicon bipolar variety. In general, the impedance levels of the circuits are higher and the speeds are slower. The construction technology is related to that described for silicon monolithic circuits. Particularly for memory applications, the MOS integrated circuit offers attractive advantages in low standby power, high density

of elements, immunity from noise, and simplicity of fabrication. Initial difficulties in stability with age appear to have been overcome. The MOS configuration is adapted to the construction of resistors and capacitors. The MOS family is an interesting complement to the bipolar family of integrated circuits.

High-density and large-scale application, typified by the digital computer, have motivated most integrated-circuit accomplishments. Applications to linear circuits are limited by lack of suitable inductances. The technology of integrated circuits brings new implements to a wide range of tasks. The example of integrated circuits for a reading aid for the blind is typical of the broadening application. In this device, which is a research project of Professor Linvill at Stanford University, print is scanned by an array of phototransistors. Circuits reproduce the resulting pattern in an array of vibratory reeds, which may be sensed by the finger of a blind reader.

In response to questions, Professor Linvill indicated that the equipment needed to fabricate integrated circuits was relatively simple and entirely suitable for laboratory use in making experimental apparatus. He also emphasized the primacy of silicon: a background of experience and technology would have to be acquired for any new material before it could be used in integrated circuits.

THE PRESENT STATUS OF THIN-FILM CIRCUITS

H. G. Manfield

Although silicon monolithic circuits can meet low-level digital needs, there are applications where thin-film circuits have promise. One of these is for devices operating at power levels beyond the capability of monolithic circuits. An example is the transistor output stage of radio receivers, which has not been displaced by integrated circuits. Prototype and specialized circuits can easily be made at small cost by thin-film technologies. The equipment required for thin-film circuit fabrication is more modest than for monolithic devices.

Circuit patterns are delineated by photolithographic methods, with deposition either by high-vacuum evaporation or sputtering. Substrates consist of glass or ceramic with a high degree of

surface smoothness. Resistive films on ceramic substrates are used in Cermet resistors, which are made in a similar manner.

The accuracy and stability of thin-film passive components, including resistors, capacitors, and inductors, is superior to those attainable in silicon integrated circuits. However, there are no adequate active elements available. Thin film CdS and CdSe transistors have been made, but they show no signs of becoming reliable and reproducible devices. To provide active elements, transistors and diodes on chips may be bonded to the thin-film circuit by the so-called flip-chip method.

The advantages of both superior passive components and active elements may be realized by a new technique known as silicon on sapphire. In this approach, silicon semiconductor elements are deposited by epitaxy onto passive substrates of pure single-crystal sapphire. Excellent passive elements can be made on the same substrate by vacuum deposition. Although still fraught with difficulties, this method may eventually offer the best over-all characteristics for microelectronic circuits.

In response to questions, Manfield affirmed that thin-film circuits were adapted to mass-production techniques. Although a wider range of passive component values is available on thin films than in monolithic silicon, there are definite limits to the maximum inductance and capacitance they can attain. Correspondingly, the useful frequency band lies from 10 MHz to 100 MHz and up.

COMMISSION VII / SESSION OF SEPTEMBER 12 (P.M.)

Solid-State Plasmas, Helicons, and Gunn Effect

CHAIRMAN: PROF. R. E. BURGESS (CANADA)

The Chairman opened the session with comments on the current importance of solid-state plasmas and on the differences between these and the plasmas of gas discharges in the ionosphere. In the solid-state plasma, the moving charges interact not only with each other but also with the lattice environment. Charge-phonon interactions are thus important. The ratio between positive and negative charge densities may be any value desired, including values much greater than unity. Longitudinal waves are of as much interest as transverse waves. Nonequilibrium plasmas, including very hot ones and those with supersonic interactions, are of concern.

The first of three papers in this session came from the distinguished Ukrainian school, which has made many important and original contributions to plasma theory. It discusses spatial and temporal electromagnetic fluctuations and shows how nonlinearities can transform one type of wave into another. Under nonequilibrium conditions, the concept of an effective temperature may still be applicable. Ultimately, appearance of instabilities is associated with the growth of fluctuations, as the effective temperature increases indefinitely.

The second paper is concerned with propagation in good conductors (especially metals and semimetals) in a strong magnetic field where Alfvén and helicon waves appear at low frequencies with relatively low attenuation.

The third paper deals with the negative conductance arising from electron transfer from the central-band minimum to a higher band minimum in a strong electric field. This is the

mechanism of the Gunn effect oscillations, which are presently receiving intensive investigation. This is a striking example of a phenomenon which has no analog in a gas plasma.

FLUCTUATIONS IN SOLID-STATE PLASMAS

A. G. Sitenko (U.S.S.R.) and V. N. Orayeuskii (U.S.S.R.)

A more extensive treatment of the material presented in this paper has appeared in book form in Russian, and an English translation is soon to be published by Academic Press (approximate title: Electromagnetic Fluctuations in Plasmas). The abstract is a reasonably accurate summary of the talk, except that the role of spin fluctuations in coupling of waves (via magnetic interactions) was also mentioned. Parametric conversion of waves by another large-amplitude (nonlinear) wave was discussed.

THE PROPAGATION OF ELECTROMAGNETIC WAVES IN SOLID CONDUCTORS

W. Mercouroff

A more detailed discussion of the phenomena reviewed in this paper is to be found in Effets de Plasmas dans les Solides (Dunod, 1964). In addition to presenting an excellent summary of the principles of the phenomena involved, Mercouroff described a number of possible applications to devices and to the study of the properties of solids. They included:

1. A helicon isolator for low frequencies (after Veicex).
2. A helicon magnetometer for high fields (after Bowers).
3. Measurement of static dielectric constant of metals (due to bound electrons).
4. Study of the structure of the Fermi surface of metals with the use of effects of open trajectories and with the use of Landau damping of helicon waves.
5. The study of nuclear magnetic resonance, of acoustic waves, etc., in metals through their interaction with helicon waves.

TRANSFERRED-ELECTRON OSCILLATORS

P. N. Butcher (U.K.) and C. Hilsum (U.K.)

Dr. Butcher reviewed the rapid advance of solid-state devices for higher frequencies and the impact made by the discovery by Gunn in 1963 of negative-resistance oscillations in bulk n-type GaAs with applied electric fields above a threshold value. He noted that this is still the best material for practical oscillators, although the effect has since been found in InP, CdTe, arsenic-rich gallium, arsenide-phosphide alloys, and indium arsenide under hydrostatic pressure.

The presently accepted mechanism of oscillations was described. The energy diagram in k space has a minimum (for the 100) direction at k = 0, called the central valley with a low effective mass of 0.067, whereas other satellite valleys at the edges of the Brillouin zone in the three (100) directions have higher energy and effective mass (energy separation is 0.36 eV and effective mass is estimated at 0.35). At high fields, energy is fed into the electrons and they become sufficiently hot to move from the central volley to the satellite valleys. The average electron mobility consequently decreases and the average velocity versus field curve consequently shows a negative resistance behavior over a certain region, with a threshold electric field for such an effect. Extensions and refinements of this simple basis were described.

The author next described analyses by himself and his co-workers of the propagation of stable domains having a narrow region of high field moving through the specimen. The simplest model neglects the effect of the field dependence of the diffusion coefficient and results in a domain velocity equal to the electron-drift velocity outside the domain. The peak field is also determined. In the limit of zero diffusion, the domain has a simple triangular shape, but it is rounded when diffusion effects are included. Measurements to verify the results are difficult to make, although Gunn has very recently reported the resolution of triangular-domain shapes with fully depleted layers at the leading edge in 10 Ω/cm GaAs. The effect of bias field was described. Some numerical calculation, including the effect of the field-dependence and of the diffusion coefficient were described, yielding changes in domain velocity, but effects generally similar to those of the simpler model.

In addition to high-field domains, moving accumulation layers, depletion layers, and low-field domains are possible and have been studied.

The interactions of the Gunn material with a cavity include the "transit-time" mode when the transit-time of domains is equal to the period of the resonant cavity—the "resonant" mode—which occurs when the cavity frequency is higher than the transit frequency, and the "overshoot" mode, where the cavity is at a lower frequency than the transit frequency. The second of these is most important in reaching high frequencies. The last has been analyzed in detail with respect to tuning range, operating voltage, and efficiency.

The material technology for practical GaAs Gunn oscillators was discussed, and practical oscillators built at the Radar Research Establishment (RRE) were described. These used a 10-μ epitaxial layer of pure GaAs deposited on a substrate of heavily doped n-type GaAs. The anode is a tin-coated molybdenum cylinder, and the cathode is a small tin dot alloyed on the epitaxial layer. These devices, placed in a coaxial cavity, give between 10 and 50 mW of power at 10 GHz, with efficiencies between 1 and 5 percent (cw), and up to 1 W when pulsed with 1-μsec pulses at a 100-kc rate. Results obtained elsewhere were also described.

The discussion brought out the possibility of using the Gunn effect in amplifiers, but poor noise figures result.

Cryogenic Coils

CHAIRMAN: D. B. MONTGOMERY (U.S.A.)

THE TECHNOLOGY AND APPLICATION OF SUPERCONDUCTING MAGNETS

D. B. Montgomery (U.S.A.)

The technology of superconducting magnets has now developed to the point where it can take full advantage of the range of superconducting materials available. This has already resulted in the development of a sizeable number of successful applications. These successes serve both as encouragement for further applications and as guides for areas in which improved technology is desirable.

The availability of uniform high-quality materials has been a major factor in the developing magnet technology. The use of high-quality plating, cabling techniques, and composites of superconducting and nonsuperconducting materials have all made possible the development of predictable and reliable magnets of all sizes. Some composites have sufficiently high conductivity in the nonsuperconducting region that the magnetic field in large coils can be made stable against collapse at the superconducting-to-normal transition. In addition to high quality NbZr and NbTi alloys, the intermetallic Nb_3Sn is now readily available in several useful forms. This higher-field material should allow the construction of practical magnets approaching 200 kG.

Superconducting magnets are now in use in virtually every branch of physics. Laboratory scale coils have been used for a wide variety of solid-state physics experiments, in many cases with room temperature access, absolute stability of the

persistent current mode, very high homogeneity, and transverse access to the field. In several instances, fields over 100 kG have been achieved. In some important cases the coils have formed an integral and uniquely necessary part of electronic devices, such as TWM tubes, detectors, and millimeter wave generators. Superconducting magnets have already been applied in nuclear physics for a 50-kG 10-inch bubble chamber, ionography, polarizing and deflecting magnets, and most recently short focal length quadrupole lenses. In plasma physics, superconducting magnets have been used to provide mirror fields, minimum B-field configurations, and fields for model MHD generators, the latter being of extremely large size. In all these areas, magnets being constructed or considered far exceed those already operating, both in scope and in number.

All superconducting magnets share the requirement of a 4.2° K cryogenic environment. This is a relatively expensive environment to maintain, particularly under nonlaboratory or special conditions. More economical and successful solutions than those in current use are called for to accomodate the increasing number of potential applications. In addition, the large physical scale of some of the contemplated magnets and the increasing use of higher current carrying conductors make new solutions imperative. Developments in flux pumps, simpler closed-cycle refrigerators, new dewar materials and constructions, and remote helium-circulating systems will all make contributions toward this end.

This review dealt with superconducting magnet technology, with the cryogenic environment, and with application of the magnets. The interrelation between these three factors was emphasized. In addition to this general treatment, the review incorporated abstracts (by other authors) of the following special areas: the potential application of superconducting magnets to electronic devices; the application, economics, and characteristics of laboratory scale magnets; the technology of large coils; and the technology of niobium-tin magnets.